DESIGN OF GAS-COOLED TEST LOOP FOR NASA PLUM BROOK REACTOR FACILITY

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CONTENTS

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SUMMARY

A recirculating gas-cooled inpile loop facility is described. The inpile section of the loop is designed to fit into the horizontal test hole, HT-1, of the NASA Plum Brook Reactor Facility. The thermal neutron flux in HT-1 is 4×10^{14} neutrons per square centimeter per second. Pertinent features of the loop are as follows:

(1) The main coolant system is a closed loop filled with helium gas at a pressure of 200 pounds per square inch absolute.

(2) Test specimens generating up to 200 kilowatts of nuclear heat can be investigated in the loop.

(3) A bypass flow arrangement in the helium gas system allows the gas flow rate through the test section to be varied from 0.06 to 0.24 pound per second.

(4) Maximum gas temperature in the test section is limited by the physical properties of the removable test section.

(5) Double containment is used throughout the main coolant system to prevent any fission products from eminating from the experiment.

(6) The loop is packaged for movement between the reactor and the radioactive materials handling laboratory, or hot lab.

Instrumentation is provided at the test section so that heat transfer and gas flow dynamic characteristics of reactor fuel element configurations can be obtained.

INTRODUCTION

Nuclear reactors are being utilized as a heat source for electrical power generating plants, rocket propulsion engines, and aircraft propulsion systems. Major efforts are being conducted in the research and development of fuel elements for the proposed reactors. These elements can be best evaluated by reactor in-pile experiments.

To accomplish these experimental investigations, the Lewis Research Center
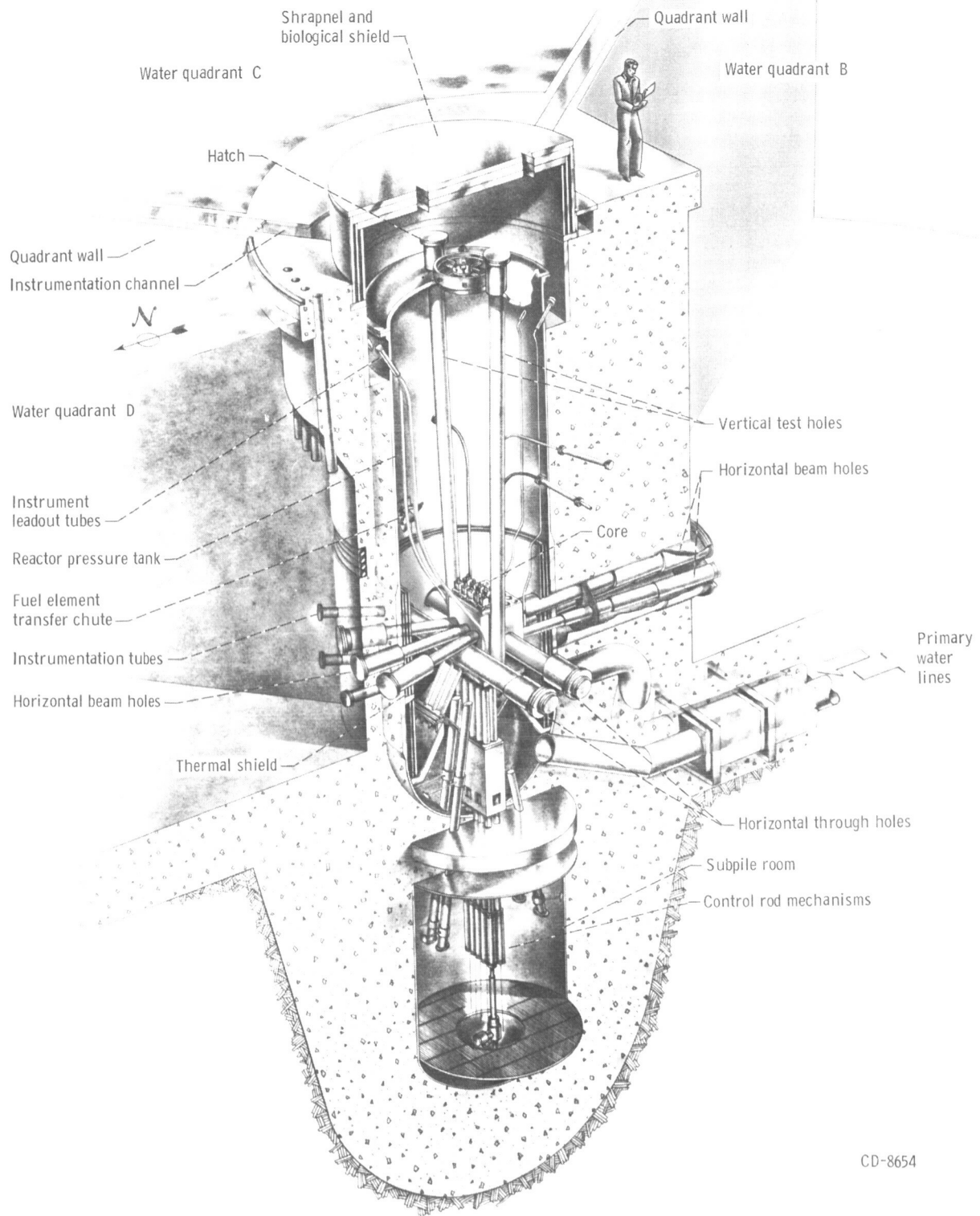
Figure 1. - Cutaway perspective drawing of reactor tank assembly.

The following labels appear in the figure:

- Shrapnel and biological shield
- Quadrant wall
- Water quadrant C
- Water quadrant B
- Hatch
- Quadrant wall
- Instrumentation channel
- N
- Water quadrant D
- Vertical test holes
- Horizontal beam holes
- Instrument leadout tubes
- Core
- Reactor pressure tank
- Fuel element transfer chute
- Primary water lines
- Instrumentation tubes
- Horizontal beam holes
- Thermal shield
- Horizontal through holes
- Subpile room
- Control rod mechanisms

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designed and constructed a recirculating helium gas-cooled loop to operate at the Plum Brook Reactor Facility. The inpile portion of the loop is designed to fit into the horizontal test hole identified as HT-1. The hole is adjacent to the core, through the beryllium moderator. The thermal neutron flux level is about 4×10^{14} neutrons per square centimeter per second in this hole. A cutaway drawing of the reactor tank showing HT-1 is given in figure 1.

This report describes the loop facility, the test procedure and the hazards considerations. Major design analyses, determination of calibration, and response time of the instruments, and preirradiation checkout tests are presented in the appendixes.

Test Objectives

The major test objectives are to study materials, geometry, and structural characteristics of proposed gas-cooled fuel elements. The tests are to be conducted at simulated heat flux, neutron flux, coolant temperature, surface temperature, and gas dynamic conditions.

Instrumentation is available in the loop so that data can be obtained to determine or observe the following characteristics:

(1) Heat-transfer coefficients
(2) Pressure drop of coolant
(3) Surface temperatures
(4) Gas coolant temperatures
(5) Fission product releases
(6) Element specific power

Design Concept

Safe operation of the loop at all times is of prime importance. Any credible accident during operation of the loop will physically damage only the loop equipment and will not be dangerous to the Plum Brook Reactor Facility or its personnel.

Throughout the loop, two barriers exist between the helium coolant and the reactor building atmosphere or the reactor water cooling system. This concept provides the experimenter with a monitoring medium to detect ruptures in either the inner or outer barriers of the helium system. Helium was selected for the principle coolant of the loop because the gas is inert and has limited activation; however, it may carry fission product activity released by the fueled test specimens. For this reason containment is essential.

In addition, all the equipment and piping are enclosed by the equipment tank. The tank forms a second barrier for any equipment or piping not complying with the double containment feature.

The space between pressure barriers within a piece of equipment and the atmosphere in the tank is monitored for pressure rises during loop operation. An abnormal rise in pressure would indicate a leak in one of the barriers. The loop operator is automatically warned of the prevailing conditions, and he can initiate a reactor power reduction.

The water shield surrounding the Plum Brook Reactor Facility and the water canals from the reactor to the radioactive materials handling laboratory (hot lab) are also used to shield the activated loop experiment. For this reason, the loop is designed for underwater operation and movement. A layout of the water quadrant and canals is shown figure 2. This unique feature of transportability between the hot lab and the reactor presented special design and handling problems.

Ease of maintenance and repair is also important because of the activity connected with inpile equipment. For this purpose, a hot lab rig was designed for this loop which
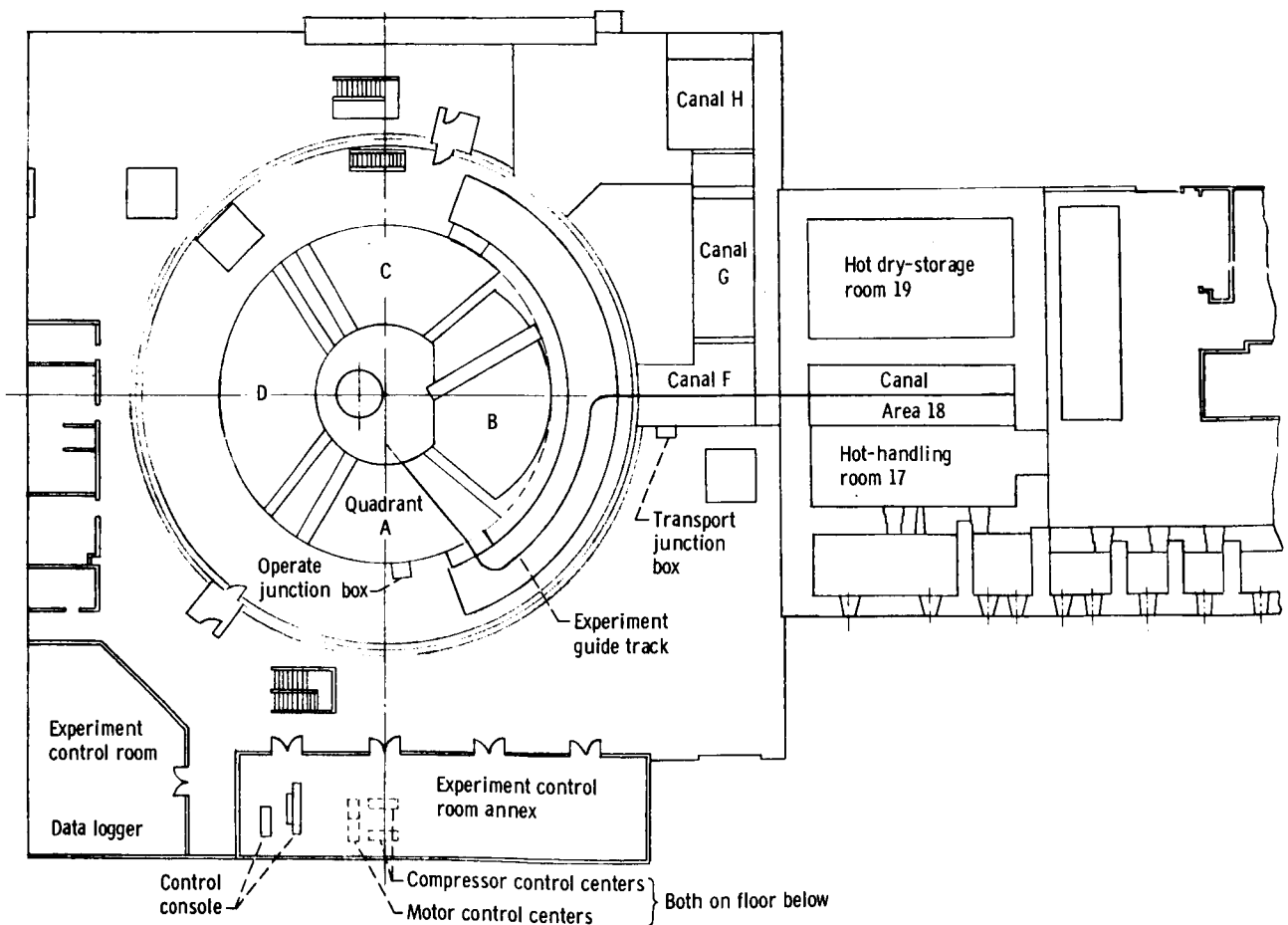
Figure 2. - Reactor building layout.

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can rotate the entire loop remotely. With the top and bottom covers removed, all the major components are exposed and can be worked on.

Operating Characteristics, Limitations, and Requirements

The operating characteristics of the loop for 100 and 200 kilowatts are listed in the following table:

Operating characteristic	Specimen power, kW	
	100	200
Helium gas flow rate (max), lb/sec	0.24	0.24
Helium gas test section inlet temperature, ^{O}F	257	360
Helium gas test section inlet pressure, psia	201	227
Helium gas test section outlet temperature, ^{O}F	577	1000
Compressor inlet temperature, ^{O}F	162	265
Compressor inlet pressure, psia	174	200
Heat exchanger water flow rate, gal/min	21	21
Heat exchanger water inlet temperature, ^{O}F	65 to 85	65 to 85
Heat exchanger outlet temperature, ^{O}F	108 to 128	140 to 160
Perturbed flux (estimated), neutrons/(cm^2)(sec)	1×10^{14}	1×10^{14}
Duration of test (estimated), kW hr	2000	2000

The loop is designed for a maximum heat generation rate of 200 kilowatts; however, the initial test will be held within the following limitations in order to provide wide margins of safety:

(1) The test specimen heat generation rate shall not exceed 100 kilowatts during normal full-power operation of the reactor.

(2) The maximum fission energy produced during one test specimen irradiation shall not exceed 2000 kilowatt-hours.

(3) During credible accidents or malfunctions, the test specimen surface temperature shall remain below the melting point of the matrix material or below the melting point of the fuel specimen when no matrix material is used. In addition, the wall temperature of the inpile tube aluminum pressure vessel shall not exceed 320° F.

In order to meet these requirements, automatic reactor power reductions are initiated by the following conditions:

(1) Low test specimen helium flow
(2) Low inpile tube inlet helium pressure
(3) High test specimen outlet gas temperature
(4) High inpile tube wall temperature (aluminum outer pressure vessel)
(5) High inpile tube static jacket helium pressure
(6) High sump water level
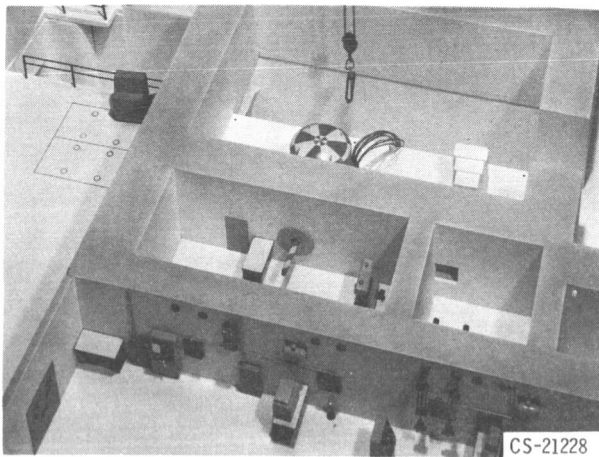
(a) Inpile tube inserted into hot cell.
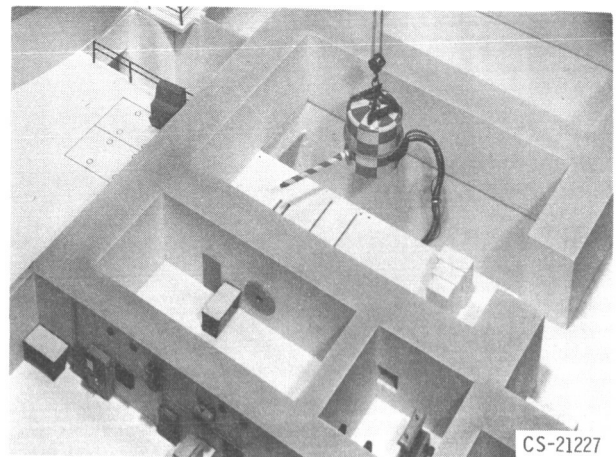
(b) Removal of loop from hot cell.
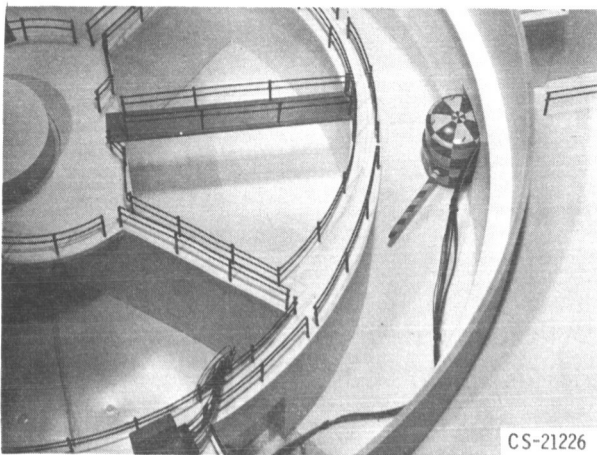
(c) Loop passing through canal door.
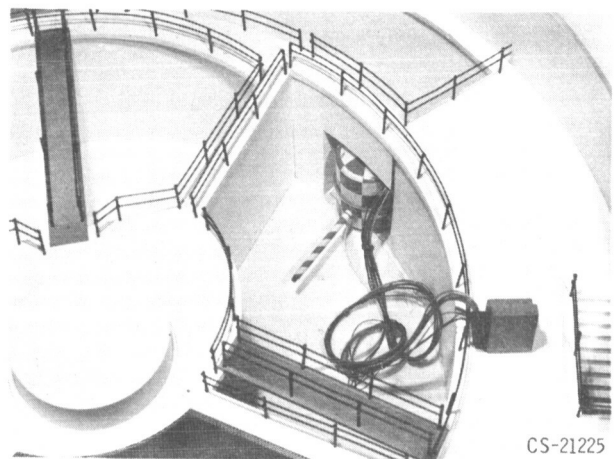
(d) Loop passing through quadrant door.
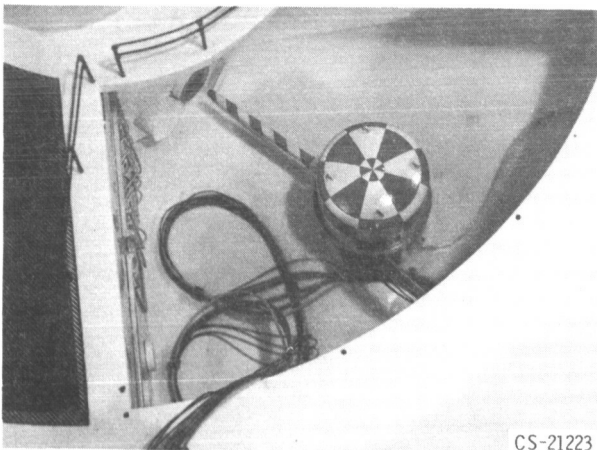
(e) Loop in quadrant A.
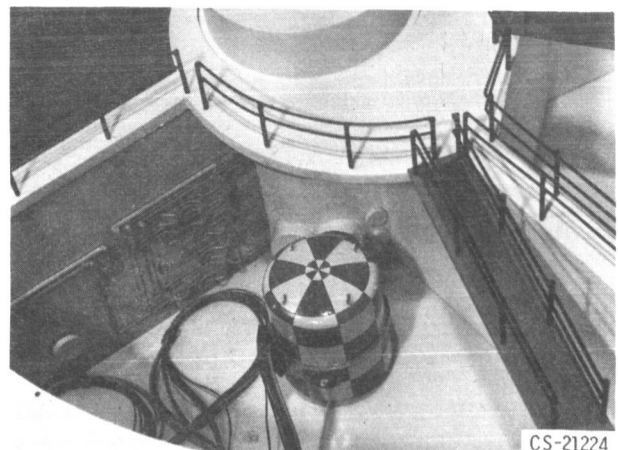
(f) Loop inserted into reactor.

Figure 3. - Experimental procedure.

Test Procedure

The procedure for conducting a typical test is described in the following paragraphs and is illustrated with scale models in figure 3: In the hot lab, the test section assembly is inserted into the inpile tube, which is then sealed and leak checked (fig. 3(a)). A preliminary checkout of the loop follows. The helium system and equipment tank are evacuated just before the loop is transported to quadrant A. The loop is then submerged into the hot lab canal water (~25 ft) and transported to quadrant A of the reactor (figs. 3(b), (c), and (d)). In quadrant A, the water lines and electrical cables are connected, and the helium system and equipment tank are charged with helium and nitrogen, respectively. An extensive operational checkout is then made. After the checkout, the in-pile tube is inserted into the HT-1 test hole (fig. 3(f)). The loop is now ready for irradiation. The reactor is started after the loop is operating at the required pressure and flow conditions. When the test run is completed, the reactor is shut down, and the loop is removed from HT-1.

After the loop is removed from HT-1 (fig. 3(f)), one or both of the compressors may continue to operate to remove the afterheat from the test element and the inpile tube. During the cooldown period, the loop is transported underwater through the canal system to the hot lab (figs. 3(c) and (d)), and the afterheat is transferred to the canal and quadrant water. When the cooldown period is completed, the compressors are stopped, and the loop is lifted out of the canal (fig. 3(b)). The inpile tube is then inserted into the hot cell for remote removal of the test specimen (fig. 3(a)).

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Figure 4. - Equipment tank and inpile tube.
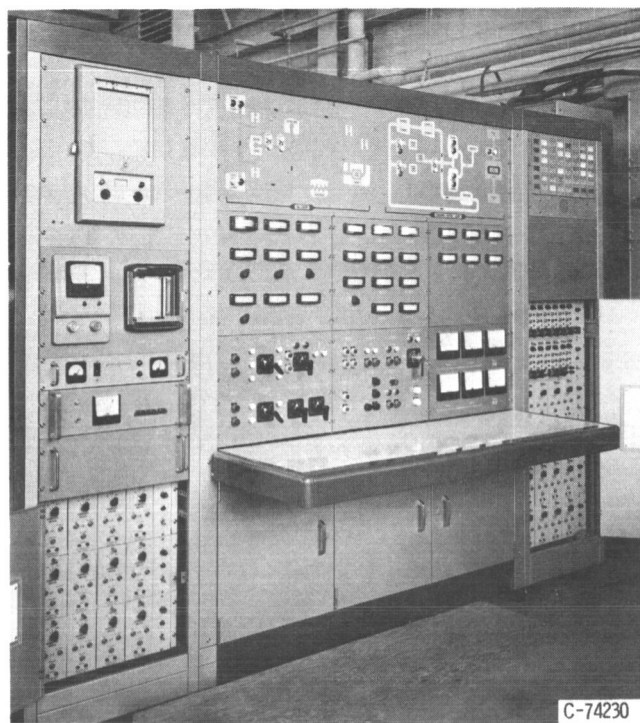
(a) Bays 1 to 5.
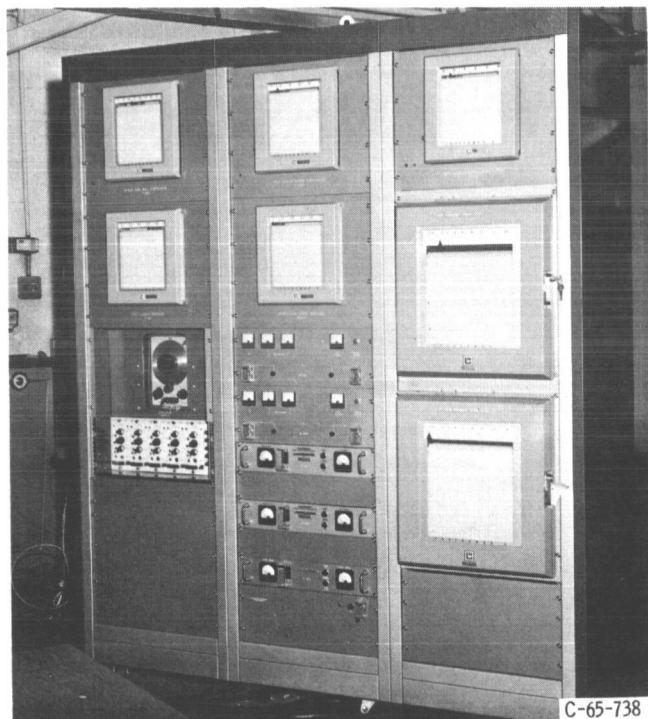
(b) Bays 6 to 8.

Figure 5. - Control console.

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Figure 6. - Motor control centers 1 and 2.

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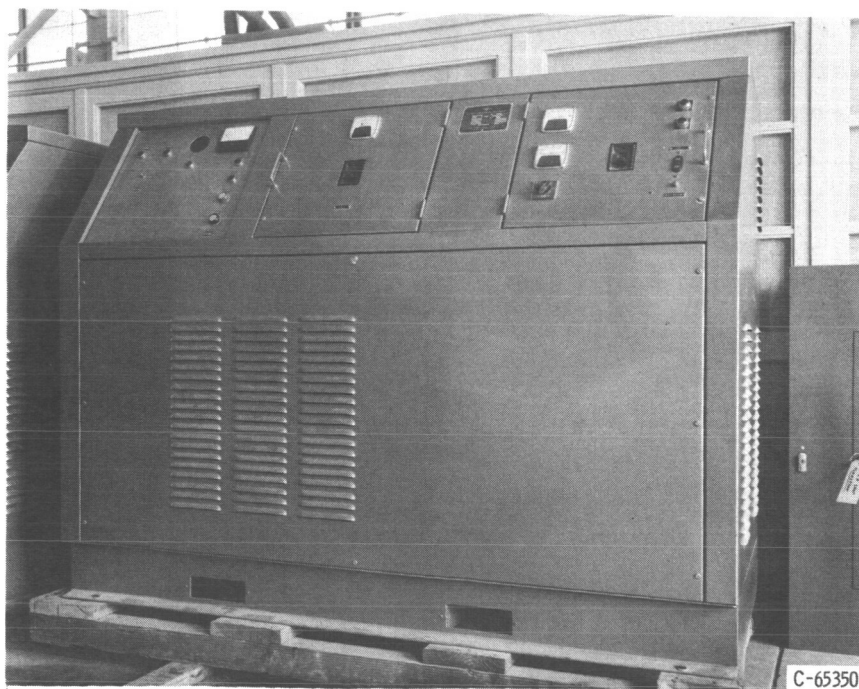
Figure 7. - Typical compressor control center.

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Description of Loop Facility

The complete loop facility consists of an equipment tank with integral inpile tube, control console, motor control center, and compressor control centers. Photographs of these components are shown in figures 4, 5, 6, and 7, respectively. These components are interconnected with flexible instrument and power cabling. Flexible lines supply cooling water from the reactor facility.

A transport system is used to haul the tank to and from the reactor and hot lab. This system consists of an electrically powered cart guided by a continuous track on the floor of the canals and quadrants. Rails on the floor of the quadrant and in the hot lab guide the inpile tube into the test hole and into the appropriate opening in the hot lab dismantling room.

Loop

The loop consists of an inpile tube and an equipment tank.

Inpile tube. - The in-pile tube contains the flow channels to direct the helium coolant to the test section, which is housed in this portion of the loop. Inside the tube, the necessary instrumentation interconnections are provided to measure surface temperatures of test specimens as well as temperatures, pressures, and pressure differentials across helium-loop components.

Basically, the inpile tube consists of an aluminum and a steel pressure vessel. The steel pressure vessel is inside the aluminum vessel and is divided into two sections. The section that holds the test specimen is adjacent to the reactor core during irradiation. The second section is contiguous to the equipment tank and is filled with water to attenuate nuclear streaming into the equipment tank.

Equipment tank. - The equipment tank houses all the mechanical equipment necessary for the operation of the loop. This includes helium compressors, supply and surge tanks, valves, heat exchanger, filter, water pumps, and piping. The tank also supports the inpile tube. Four wheels position the tank assembly on guide rails for proper alinement with the HT-1 test hole and the hot-cell remote handling accommodations. Instrument and power cables from the tank couple the equipment in the tank to the control console, M-G set, and motor control center. Flexible metal hoses connect the Plum Brook Reactor Facility water systems to the tank water system. Lead ballast is attached to the tank to overcome buoyancy while the tank is submerged in the reactor quadrant and canals.

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Control Console and Data Logger

The control console houses the instruments, controls, and power control circuits necessary to operate the loop and is located in the Experiment Control Room Annex. All instrument channels read out on the control panel by means of indicating meters or strip chart recorders. Selected instrument channels are also recorded on the Plum Brook Reactor Facility data logger.

The data logger consists mainly of two integrated pieces of equipment, a medium-speed digital computer and an online control group. The system has such features as a paper tape reader, a paper tape punch, and a manual control and display cabinet, which provides input-output communications with the computer. Various analog signals from the experiment console are fed to the computer through an analog-to-digital converter.

Motor Control Center

Electrical power for the experiment is supplied through a motor control center consisting of normal and emergency sections that are structurally and electrically isolated from each other. The control center contains circuit breakers, transformers, starters, and transfer switches for power supply to water pumps, sump pump, control console, and compressor control centers. Starters and transfer switches are remotely operated from the control console. The motor control center is located at the basement level of the reactor building.

Compressor Control Center

There are two identical compressor control centers, each supplying electrical power to a compressor. Each control center has a 60-kilowatt, 440-volt, 400-cycle output motor-generator set with associated circuit breakers, a starter, control circuits, a transfer switch, indicating lights, and meters. The compressor control centers are also located at the basement level.

System Design and Analysis

The overall flow diagram for the loop is shown in figure 8. The thermodynamic state points shown in this figure are calculated values for test-specimen heat-generation
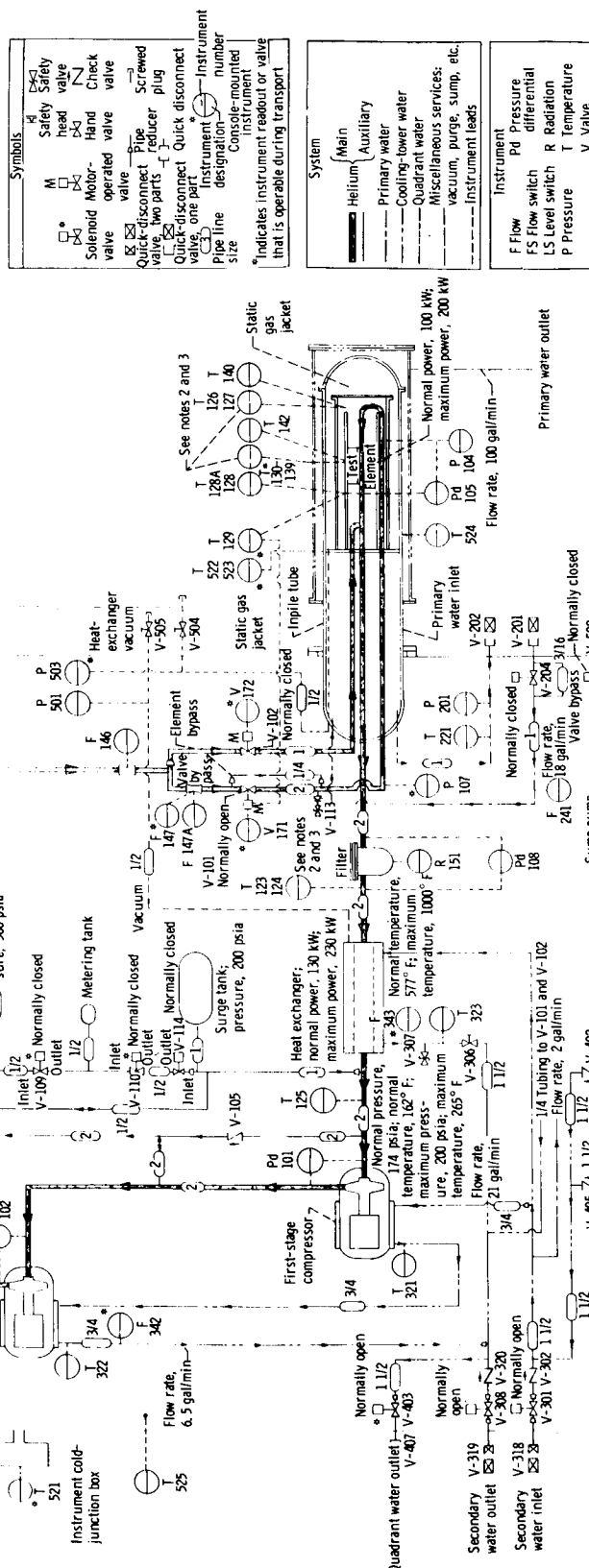
Figure 8. - Piping and instrumentation diagram. (All dimensions are in inches.)

1. During transport all reactor control functions are disconnected.
2. Temperature signals available while in transport are 123, 129, 131, 134, 137, and 522.
3. Selector switch on console for readout of either signal. All signals readout on data logger.

Symbols

Solenoid valve
M Motor-operated valve
Hand valve
Safety valve
Check valve

Quick-disconnect valve, two parts
Pipe reducer
Screwed plug

Quick-disconnect valve, one part
Instrument designation
Console-mounted instrument

Pipe line size
Quick disconnect
Instrument number

*Indicates instrument readout or valve that is operable during transport

System

Helium { Main
Auxiliary }
Primary water
Cooling-tower water
Quadrant water
Miscellaneous services: vacuum, purge, sump, etc.
Instrument leads

Instrument

F Flow
FS Flow switch
LS Level switch
P Pressure
Pd Pressure differential
R Radiation
T Temperature
V Valve

rates of 100 kilowatts and for the design maximum of 200 kilowatts.

The primary flow system for the experiment is the helium coolant system. The helium takes away the heat from the test specimen and gives it up to the heat exchanger within the system.

During normal operation of the loop in the reactor quadrant, the compressors, heat exchanger, and all other equipment in the tank are cooled by a closed reactor water supply system. While the loop is being transported between the reactor and the hot lab or during an emergency, the water filling the quadrant or canal is pumped through the water cooling system within the equipment tank.

Helium System

Two compressors connected in series recirculate helium through the loop. The compressors operate at constant speed so that a constant weight flow of 0.24 pound per second (design value) exists in the loop. The head rise across the two compressors is 37 200 feet of gas or 27.0 and 26.6 pounds per square inch absolute at 100- and 200-kilowatt operation, respectively. The compression temperature rise of the helium is from 162° to 257° F and from 265° to 360° F for the 100- and 200-kilowatt cases, respectively, which is equivalent to a heat input of approximately 30 kilowatts. The pressure rise through the compressors is from 174 to 201 pounds per square inch absolute and from 200 to 227 pounds per square inch absolute for the 100- and 200-kilowatt operating points.

Prior to entering the inpile tube or test section, the helium is divided into two paths: one path directs the helium through the test section, and the other directs it through a bypass line. The flow rate through the test section can be varied from a minimum of 0.06 pound per second to a maximum of 0.24 pound per second by adjusting the main throttle valve V-101 and the bypass valve V-102. This arrangement allows the outlet gas temperature of a given test specimen to be varied over a wide range. The test-section and bypass gas flows recombine and mix a few inches downstream of the test specimen. The operation of the loop is simplified with the bypass feature because the temperature of the mixed gas remains constant for a given system heat load. Variations in helium flow through the test section will not change the temperature of the gas entering the heat exchanger. In addition, the only portion of the loop that will be exposed to the high-temperature gas ($>1000^{\circ}$ F) is in the test section between the test-specimen outlet and the bypass flow mixing region.

Valve V-101 is capable of either manual or automatic operation. In the automatic mode, it is controlled by a thermocouple (T-129), which monitors the test specimen exit gas temperature (see fig. 8). Valve V-102 is manually controlled. The flow

through this valve varies from a maximum of 0.18 pound per second to zero. The total flow, test specimen plus bypass, is indicated by flowmeter F-146. The gas flow through the test section (or test specimen) is indicated by flow recorders F-147 and F-147A. The filter downstream of the test section will remove particles from the helium gas stream. The highest system temperature (excluding the test section) is 1000° F, which exists between the bypass flow mixing region and the heat exchanger inlet.

The heat exchanger, which follows the filter, is a gas-to-water type. With a gas flow rate of 0.24 pound per second and inlet gas temperatures of 577° and 1000° F, the heat removal rates are 130 and 230 kilowatts, respectively. The exit gas temperatures are 162° and 265° F, respectively. (As was previously noted, the heat input from the compressors is 30 kW.)

The helium system is pressurized in the following manner: Prior to operation, the system will be charged to a pressure of approximately 140 pounds per square inch absolute. During operation, the system pressure will be raised to the desired operating pressure by introducing helium at 500 pounds per square inch absolute from the supply tank T-106 through valves V-109, V-110, and V-114 (see fig. 8). For reasons of safety, tank T-106 was designed so that the system pressure would not exceed 250 pounds per square inch absolute if the tank was accidentally emptied into the helium system. Again for safety reasons, no provisions are made for the removal of helium from the system during operation. Pressure surges are minimized by a loop surge tank T-107 that increases the loop volume by a factor of 2.

Water Systems

The following water systems of the Plum Brook Reactor Facility are used for cooling or nuclear shielding in the loop:

(1) Primary water: Cool the reactor core and any items in the test holes, such as the shield water in the inpile tube.

(2) Secondary water: Cool any out-of-pile experiment equipment, such as the compressors or heat exchanger.

(3) Quadrant water: Water in the canals and the quadrants surrounding the reactor, which serves as a radiation shield for the reactor.

The titles of these systems may indicate their importance in Plum Brook Reactor Facility, but they are not indicative of their importance for this loop.

Inpile tube cooling. - Heat is removed from the inpile tube by circulating primary water through a radial gap of about 1/4 inch between the outside diameter of the inpile tube and the inside diameter of test hole HT-1. For a flow rate of 100 gallons per minute, the temperature of the coolant water rises about 10° F. The maximum rate of

heat removal at the reactor centerline is approximately 100 000 Btu/(hr)(sq ft) at full reactor power.

Inpile tube nuclear shield water. - Primary water is circulated through a portion of the inpile tube to form a shield to attenuate nuclear streaming into the equipment tank. The helium supply and return lines to the test section go through the shield-water pressure vessel. These lines are spiraled to prevent neutron streaming through the lines and into the equipment tank. To provide double containment between the helium and the primary water, the helium inlet and exit lines are each enclosed by a second gas-tight barrier. This second barrier consists of a flexible bellows tube. Calculations show that the water flow of 18 gallons per minute through the water shield vessel is sufficient to prevent boiling on the surface of the flexible lines.

Secondary water system. - The Plum Brook Reactor Facility secondary water system supplies coolant to the heat exchanger, the two compressors, and the helium throttle valves. The water to the compressors cools only the motor housing. The heat of compression is removed through the main heat exchanger. A maximum of 234 kilowatts will be dumped into the secondary cooling water system: 230 kilowatts from the heat exchanger and 2 kilowatts from each compressor motor.

Quadrant water system. - As stated earlier, quadrant water provides coolant to the heat exchanger, compressors, and the helium throttle valves while the loop is being moved. The quadrant water also serves as an emergency supply to back up the secondary water system during irradiation tests.

The quadrant water system consists of a main water pump (P-402) and a standby water pump (P-401) connected in parallel with necessary piping to circulate water through the secondary water system. Each water pump is capable of circulating 27.5 gallons per minute of quadrant water against a differential pressure head of 29 pounds per square inch. This flow rate and pressure differential is sufficient to remove the total heat generated by the loop at design conditions.

In the event of low secondary water flow to the heat exchanger and compressors, flow switches F-342 and 343 will signal an alarm, and the main water pump will start circulating quadrant water through the system. If the main water pump fails to start, the standby water pump can be started manually.

When either of the two water pumps is started, solenoid valves V-301 and V-308, the secondary water inlet and exit valves, will close, and solenoid valve V-403, the quadrant water exit valve, will open automatically.

Hot Drain and Off-Gas Systems

Water may accumulate in the sump of the equipment tank from a leak in the primary
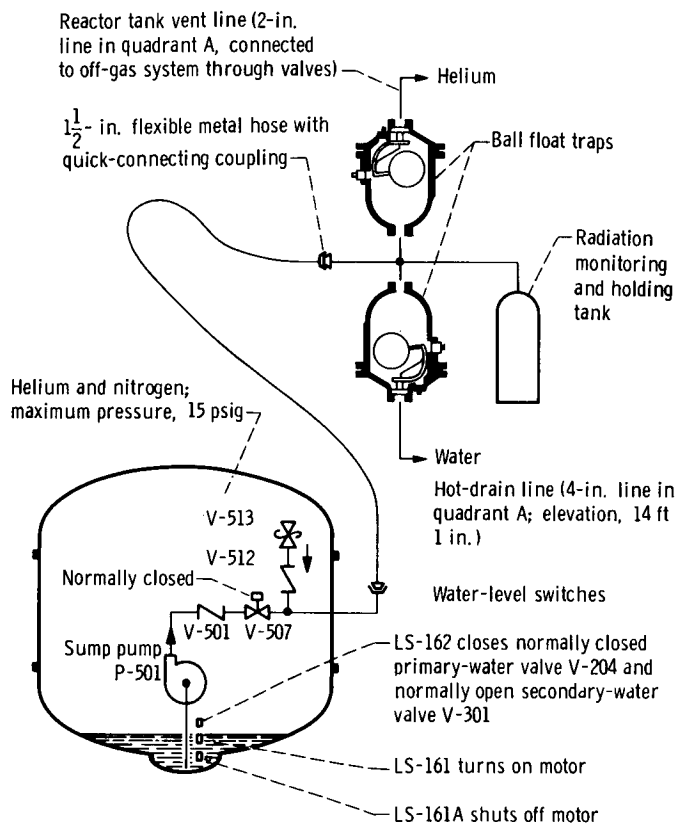
Figure 9. - Hot-drain and off-gas system.

Labels in figure:
Reactor tank vent line (2-in. line in quadrant A, connected to off-gas system through valves)

Helium

$1\frac{1}{2}$- in. flexible metal hose with quick-connecting coupling

Ball float traps

Radiation monitoring and holding tank

Helium and nitrogen; maximum pressure, 15 psig

Water

Hot-drain line (4-in. line in quadrant A; elevation, 14 ft 1 in.)

V-513

V-512

Normally closed

Water-level switches

V-501 V-507

Sump pump P-501

LS-162 closes normally closed primary-water valve V-204 and normally open secondary-water valve V-301

LS-161 turns on motor

LS-161A shuts off motor

or secondary water systems or the tank wall. Should this occur, the water will be discharged by the sump pump (P-501) through a ball float trap in quadrant A to the hot-drain line. The trapping scheme is shown in figure 9. Any radioactive gases that might be entrained in this water will be vented through a second ball float trap to the reactor tank vent line in quadrant A, which will be opened to the Plum Brook Reactor Facility off-gas system by appropriate valving. The second trap, which vents the gas, is used to separate the gas from the water and is placed above the first, with a settling or separating tank between the two.

The sump pump is started automatically by float level switch LS161 when the water level in the sump of the tank reaches this switch (3 to 6 in.). It continues to operate until the water level drops to float level switch LS161A (0 to 3 in.), at which time the pump is stopped. This action will continue as long as the water leak is not greater than the pump capacity (approx 10 gal/min). If the water leak is greater than the sump pump capacity, the water level will continue to rise until it reaches float level switch LS162 (6 to 9 in.). Switch LS162 will then close the primary water supply valve, V-204, and the secondary water supply valve, V-301. Closing valve V-204 does not completely cut off the flow since a bypass line around the valve allows a flow of 10 gallons per minute (sump pump capacity) to the shield water pressure vessel. When V-301 closes, the main water pump is started, and the loop is cooled by quadrant water, which is at a safe lower pressure. If the break in the secondary water line is large enough so that water from the main water pump continues to fill the equipment tank, a pressure relief valve vented to the hot drain and off-gas systems will prevent over-pressurization of the tank.

Electrical Systems

Reliability of the electrical power system is accomplished by having two inde

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commercial supplies to the Plum Brook Reactor Facility. These power supplies are designated high lines 1 and 2.

The power from high line 2 goes through a series of transformers and switchgear and enters the loop facility at one of the motor control centers (MCC 2). This source is referred to as normal power. The power from high line 1 differs from that of high line 2 only inasmuch as the Plum Brook Facility has four diesel-generators on line at all times to provide the necessary power if the commercial supply should fail. This source enters the loop facility at the other motor control center (MCC 1) and is referred to as emergency power. (Photographs of MCC 1 and 2 are shown in fig. 6.)

Both of these sources enter the motor control centers at 480 volts, 3 phase, and 60 cps. (The only other supplies of power to the experiment are from the Plum Brook shutdown panel and the data logger for the monitoring of the control console.)

Power distribution. - The power distribution diagram is shown in figure 10. Motor control center supplies power at 480 volts, 3 phase, and 60 cps to the standby water pump, sump pump, and to one of the compressor control centers. A transformer within the motor control center supplies 120 volts of power to panel board 2 at the control console.

Motor control center 2 supplies power at 480 volts, 3 phase, and 60 cycles per second to the main water pump and to the other compressor control center. A transformer within the motor control center supplies 120 volts of power to panel board 1 at the control console.

Both compressor control centers have motor-generator sets converting the 480-volt, 3-phase, 60-cycle-per-second supply to 480 volts, 3 phase, and 400 cps. Both 400-cycle compressor supplies are kept isolated from each other, and each supply is used to run one of the compressors in the equipment tank.

The two motor control centers, both compressor control centers, and the control console all provide power for the equipment tank. The equipment tank sends all instrumentation data to the control console and the data logger.

Cable system. - Eight multiconductor electrical cables to the equipment tank interconnect through either the operate or the transport junction boxes. A schematic drawing of the cabling plan is shown in figure 11. The operate junction box is used when the experiment is in the reactor. After the test is completed, four of the eight cables from the equipment tank are disconnected from the operate junction box and connected to the transport junction box through additional lengths of cable. These four cables are selected so that the compressors can continue to operate and the experiment monitored while it is moving to the hot lab. After this interconnection is made, the other four cables from the tank to the operate junction box are disconnected and set aside since they are not required while the loop is being moved.

The power from the motor and compressor control centers to the operate or trans-

Figure 10. – Power diagram. 480-Volt bus and 480-volt diesel busses numbers 3 and 4 are shown for reference only. Transfer switches are mechanically held to ensure selected position is maintained in event of control power loss.

Figure 11. - Cable plan.

CCC Compressor control center
MCC Motor control center
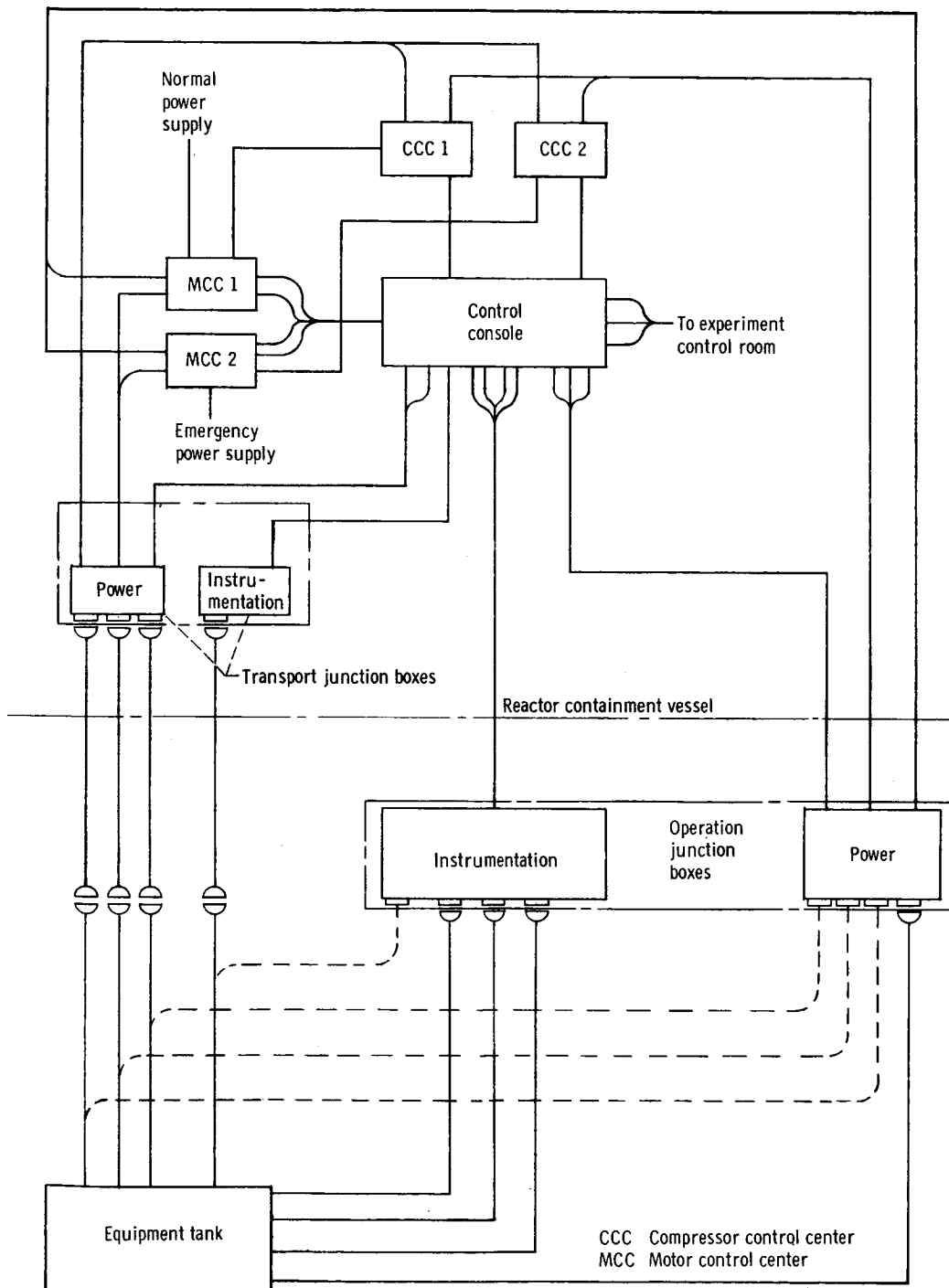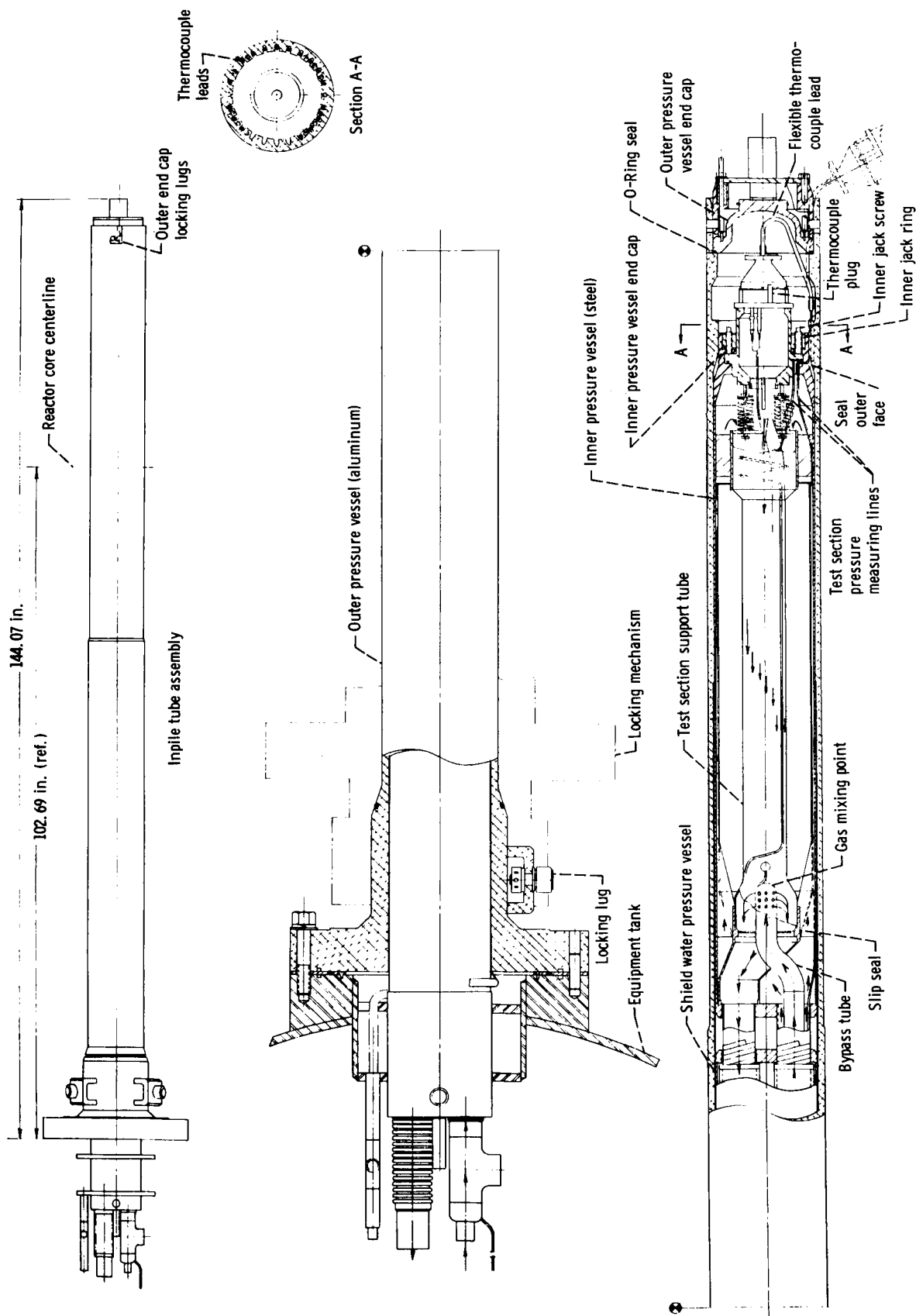
Figure 12. - Inpile tube assembly.

Section A-A

Thermocouple leads

Outer end cap locking lugs

Reactor core centerline

144.07 in.

102.69 in. (ref.)

Inpile tube assembly

Outer pressure vessel (aluminum)

Locking mechanism

Test section support tube

Locking lug

Equipment tank

Shield water pressure vessel

Bypass tube

Slip seal

Gas mixing point

Test section pressure measuring lines

Seal outer face

Inner pressure vessel (steel)

Inner pressure vessel end cap

O-Ring seal

Outer pressure vessel end cap

Flexible thermo-couple lead

Thermocouple plug

Inner jack screw

Inner jack ring

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TABLE I. - DESIGN CONDITIONS FOR INPILE TUBE

Component	Material	Maximum design temperature, $^\circ F$	Maximum pressure, psig	
			Internal	External
Outer pressure vessel	6061-T6 aluminum	300	[b]250	145
Shield water pressure vessel	321 stainless steel	360	145	[c]250
Test specimen pressure vessel	348 stainless steel	650	250	[d]145
Gas exit tube	321 stainless steel	1000	250	[e]145
Test support tube	321 stainless steel[a]	200	0	[f]23
Gas entry and by-pass tube	321 stainless steel	360	250	[g]250
Flex hose (bellows)	321 stainless steel	360	[b]250	145
Springs	Inconel X	360	----	----

[a]For initial test with orifice plate only.

[b]Assumes coolant gas leak into static helium area; normal operating pressure, 15 psig.

[c]If a coolant gas leak into the static helium area is assumed, the net external pressure would be 250 -145 = 105 psig.

[d]A water leak into static helium area was assumed. No failure would produce an external pressure that would exceed the internal pressure.

[e]Assumes water leak into static helium area.

[f]This is the maximum pressure drop across the test specimen.

[g]Maximum possible external pressure differential of the bypass tube was 23 psi.

port junction boxes is controlled by transfer switches so that only the junction box being used will have the 480 volts available. The 120-volt supply from the control console goes to both junction boxes simultaneously.

EQUIPMENT DESIGN CRITERIA AND DESCRIPTION

The principle components of the loop are described in this section. The important design analyses are given in appendixes.

Inpile Tube Assembly

A detailed drawing of the assembly is given in figure 12. Design pressures, temperatures, and materials for various parts of the assembly are given in table I. The tube was designed to meet the requirements of references 1 and/or 2. The material properties for aluminum were taken from references 2 and 3. The amount of cobalt in the stainless steel was held to 0.2 percent.

The tube is approximately 9 inches in diameter and about 12 feet long. Both inner stainless steel and outer aluminum pressure vessels have removable endcaps, so that the test assembly can be inserted and removed. The endcaps are held in place with a combination jack ring and jackscrew and are sealed with O-rings. The inner wall of the aluminum pressure vessel has 24 equally spaced grooves (see fig. 12), which contain the thermocouple leads from the test specimen to the tank. Three of these thermocouples measure the aluminum wall temperature at the reactor centerline. Two of these are at the hot side (maximum gamma heat), and the third is 180° away at the cold side (minimum gamma heat). These thermocouples sense overtemperature conditions of the final outer barrier of the inpile tube.

The thermocouple grooves and the annular space between the inner and outer pressure vessels are charged with low-pressure helium. Helium, a relatively good conductor of heat, helps transfer heat from the inner (steel) pressure vessel to the outer (aluminum) pressure vessel and finally to the reactor water flowing along the outer wall of the tube. In addition, this low-pressure helium forms a static gas jacket, which is also monitored during operation to detect pressure variations. An abnormal rise in pressure could indicate a leak in the inner or outer pressure vessels.

Nuclear radiation shielding. - Four $1\frac{1}{2}$-inch-thick steel disks plus about 30 inches of water form the shield in the inpile tube. The steel and the water attenuate the radiation streaming down the tube and reduce damage to materials in the equipment tank. Although the total thickness of the four disks is 6 inches, the effective thickness was determined to be 3.8 inches because of the staggered holes in the disks to accommodate the helium coolant supply and return lines.

Details of the nuclear calculation are given in appendix A and can be summarized as follows: Radiation damage to materials was based on a useful life of about 1300 hours. Materials were selected to withstand the indicated dose rates for the exposure time. The gamma-ray dose at the surface of the tank results in predicted radiation levels of less than 10 millirads per hour after long exposure. With shielding around the inpile tube, the equipment inside the tank could be serviced or rapaired.

Thermocouple lead interconnection. - Seventeen thermocouples were provided in the test section. The thermocouple connector developed by NASA to form the junction between the test section leads and the leadout wires is shown in figure 13, which shows typical test section assembly.

There are 34 conductors, which penetrate through the helium system, that had to be insulated from each other and from ground with a gas-tight insulation. The maximum temperature in the area of the connectors due to gamma heating was calculated to be 1000° F. The maximum temperature gradient along the conductors through the connector was calculated to be 750° F. These high-temperature gradient conditions required that
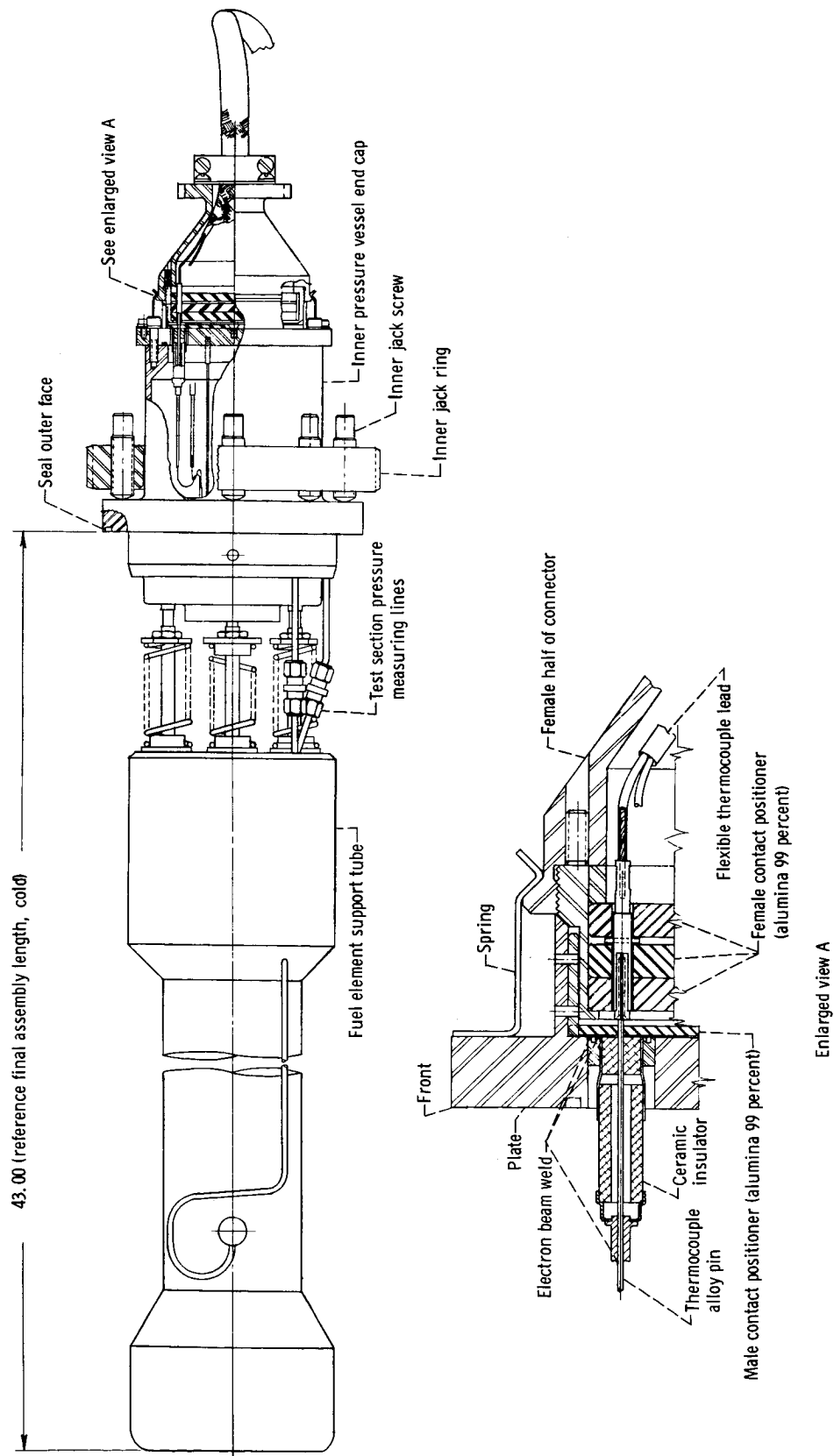
Figure 13. – Test specimen and thermal connector.

Enlarged view A

Seal outer face

See enlarged view A

Inner pressure vessel end cap

Inner jack screw

Inner jack ring

Test section pressure measuring lines

Fuel element support tube

43.00 (reference final assembly length, cold)

Female half of connector

Flexible thermocouple lead

Spring

Female contact positioner (alumina 99 percent)

Front

Plate

Electron beam weld

Thermocouple alloy pin

Ceramic insulator

Male contact positioner (alumina 99 percent)

23

the pins of both halves of the connector be made of thermocouple alloys (Chormel-Alumel and platinum - platinum 13 percent rhodium).

The assembly normally operates with a pressure difference of 200 pounds per square inch across the receptacle half of the connector. The maximum tolerable leak rate is 1×10^{-7} standard cubic centimeters of helium per second. The plug half of the connector had to be designed for remote handling with hot lab tools. The leads at the rear of the plug are flexible and long enough that the plug can be moved out of the way when the test section is being inserted or removed from the inpile tube.

The hermetic seals, which use a metal-to-ceramic seal on each end of a tubular insulator, are commercially available. A thermocouple alloy pin is inserted through the hermetic seal and sealed to the end having the small diameter tube by electron beam welding. After the seal is tested for leaks, the individual hermetic seals are inserted into a plate and sealed in by electron beam welding. The back side of the plate, where the pins protrude, forms the male half of the connector. The female half is located in the removable plug. The female pins are made of thermocouple alloys and are reinforced with Inconel springs to insure a wiping contact as the plug is inserted. The thermocouple wires and thermocouple lead wires are connected to the pins in both halves of the connector by crimping, thereby making a continuous path of thermocouple alloy through the connector.

Inpile tube temperatures and stresses. - The temperatures and stresses developed in the aluminum and steel pressure vessels are functions of the gamma heating rate, the heat-transfer coefficients on the gas and water sides, and the radial clearance between the aluminum and stainless steel pressure vessels.

A detailed temperature and stress analysis was made on the inpile tube and is presented in appendix B. The stress analysis can be summarized as follows:

(1) A Computer program was used to determine the gamma heat generation rate in HT-1.

(2) Nusselt, Reynolds, and Prandtl number analogies are used to obtain heat-transfer coefficients.

(3) Two cases were considered:

Case I: Minimum gap between the stainless steel and aluminum pressure vessels and maximum helium coolant flow through the inpile tube

Case II: Maximum gap between the stainless steel and aluminum pressure vessels and minimum helium coolant flow through the inpile tube

The results of the stress analysis can be summarized as follows:

Case I: The maximum temperatures in the steel and aluminum pressure vessels are 418° and 260° F, respectively. The design stress intensities for 348 stainless steel and 6061-T6 aluminum are 19 880 and 8160 pounds per square inch, respectively. The maximum allowable combined stresses for the steel and aluminum pressure vessels

are 59 640 and 24 500 pounds per square inch, respectively. The actual combined stresses are below these values.

The inpile tube will experience cyclic operation, but an analysis given in section N-415.1 of reference 1 shows that a fatigue analysis is not required. Thus, it can be concluded that the inpile tube is structurally safe for the conditions stated.

Case 2: The maximum temperatures in the steel and aluminum pressure vessels are 602° and 263° F, respectively. The design stress intensities for 348 stainless steel and 6061-T6 aluminum are 18 400 and 8160 pounds per square inch, respectively. The maximum allowable combined stress for the steel and aluminum pressure vessel are 55 200 and 24 500 pounds per square inch, respectively. The actual combined stresses are below these values.

A fatigue analysis is not required (as was stated for case 1). Thus, it can be concluded that the inpile tube was structurally safe for the conditions stated.

It should be noted that the temperatures and resultant stresses are based on the conservative assumption that the radial clearance between the two pressure vessels remain at the original (cold) value.

Equipment Tank

The equipment tank is a pressure vessel containing equipment, piping, and instrumentation necessary for the operation of the loop, thus making the loop self-contained. A photograph of the exterior of the tank is shown in figure 4. The general arrangement of the equipment in the tank is presented in figure 14(a). The top and bottom views of the tank are presented in figures 14(b) and (c). A detailed sketch of the exterior is shown in figure 15. The tank proper is 72 inches in diameter and 72 inches high. It consists of a center band and top and bottom covers, which are bolted to the center band. All equipment is mounted on rails or brackets attached to the center band so that top and/or bottom covers can be removed readily.

The tank was designed and tested according to reference 2 and fabricated from 1/4-inch-thick plate of AISI type 304 stainless steel. The tank is designed to meet the following maximum conditions:

Wall temperature, $^{\circ}$F 100
Differential pressure, outside to inside, psi 14.7
Differential pressure, inside to outside, psi 25.0

The surface of the tank (center band) is penetrated by 14 pipe couplings, four electrical junction boxes, and two instrument junction boxes. The inpile tube assembly
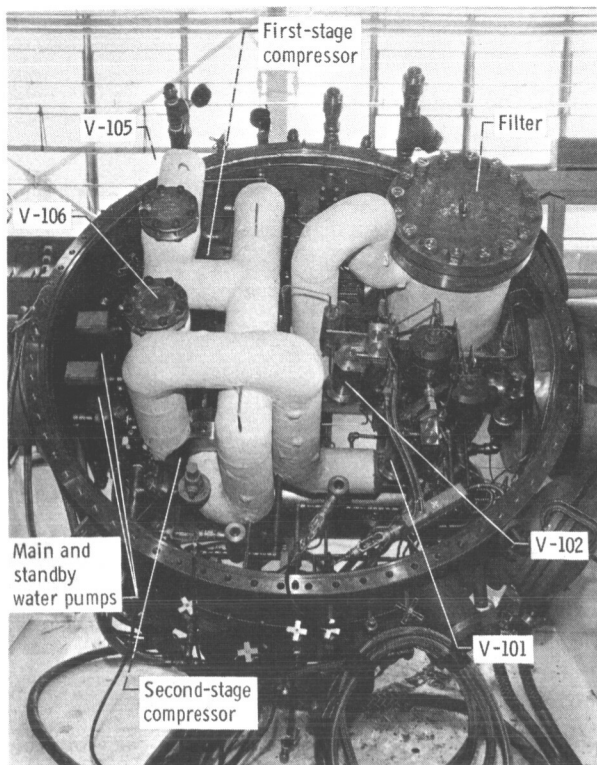
(a) Overall view.
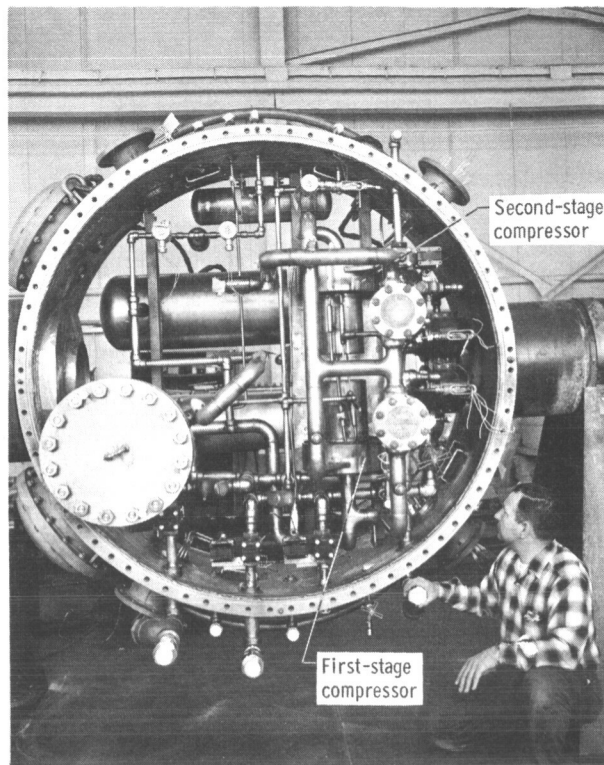
(b) Top view.
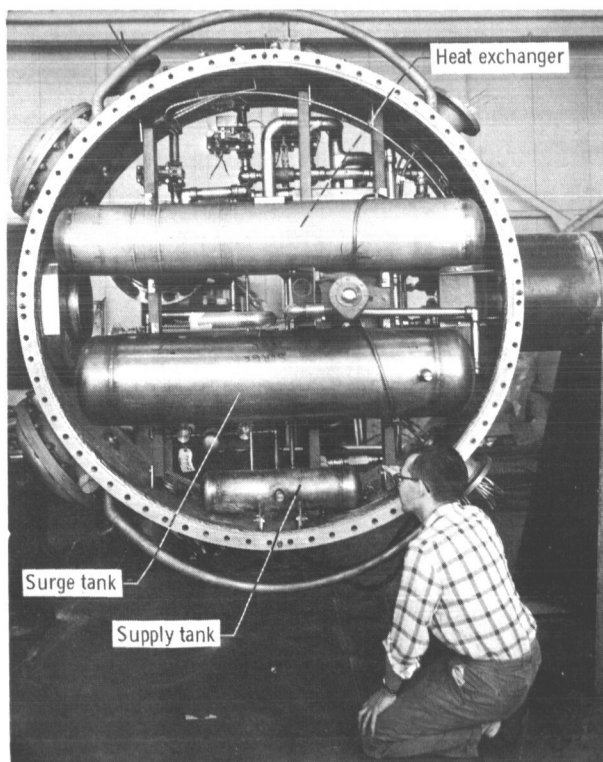
(c) Bottom view.

Figure 14. - Equipment tank.
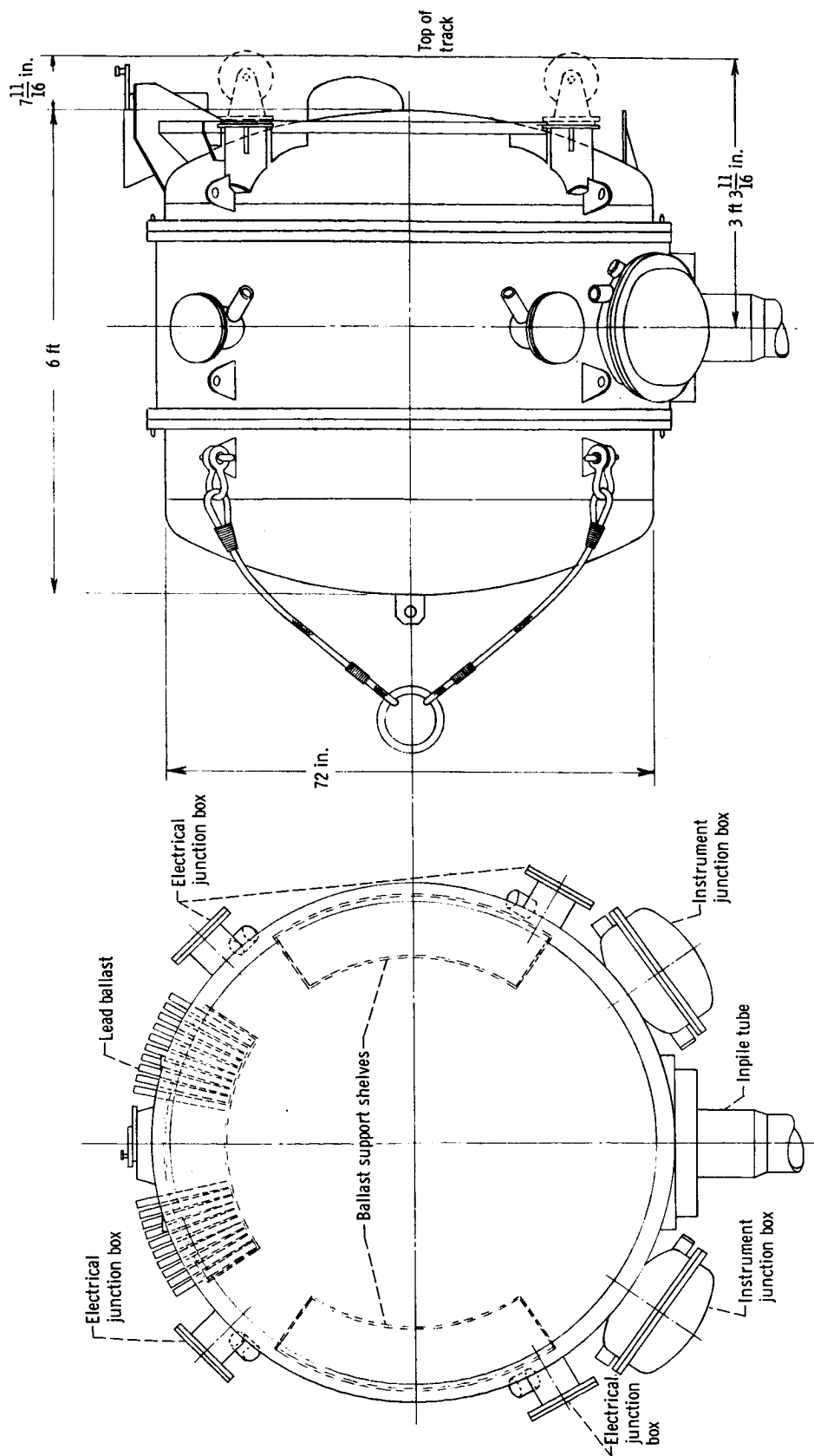
Figure 15. – Equipment tank assembly

Top of track

$7\frac{11}{16}$ in.

3 ft $3\frac{11}{16}$ in.

6 ft

72 in.

Electrical junction box

Instrument junction box

Lead ballast

Ballast support shelves

Inpile tube

Electrical junction box

Instrument junction box

Electrical junction box

27

joins the tank at a flanged center band opening. The total weight of the tube and tank, including ballast, is 11 850 pounds.

The following special attachments are included:

(1) A ballast ring on the back and sides below the bottom flange holds lead bricks for ballast, when the tank is submerged.

(2) Grooved casters, which ride rails in the quadrant and hot lab, provide for vertical and horizontal shimming, 1/2-inch in each plane, for alinement of the inpile tube in HT-1.

(3) Lifting lugs mounted on the tank body allow the entire loop to be lifted, and lifting lugs on the top and bottom covers allow the covers to be removed for maintenance.

Gas-tight and water-tight seals are provided for the instrument and electrical cable penetrations.

Helium Compressors, C-101 and C-102

The helium compressor assembly, which circulates the helium around the loop, consists of two identical centrifugal compressors connected in series. A photograph of the assembly is shown in figure 16. When only one compressor is operating, the helium flow bypasses the nonoperating compressor. The compressors and associated piping were designed, fabricated, and pressure tested according to the procedure reference 2.

C-65346
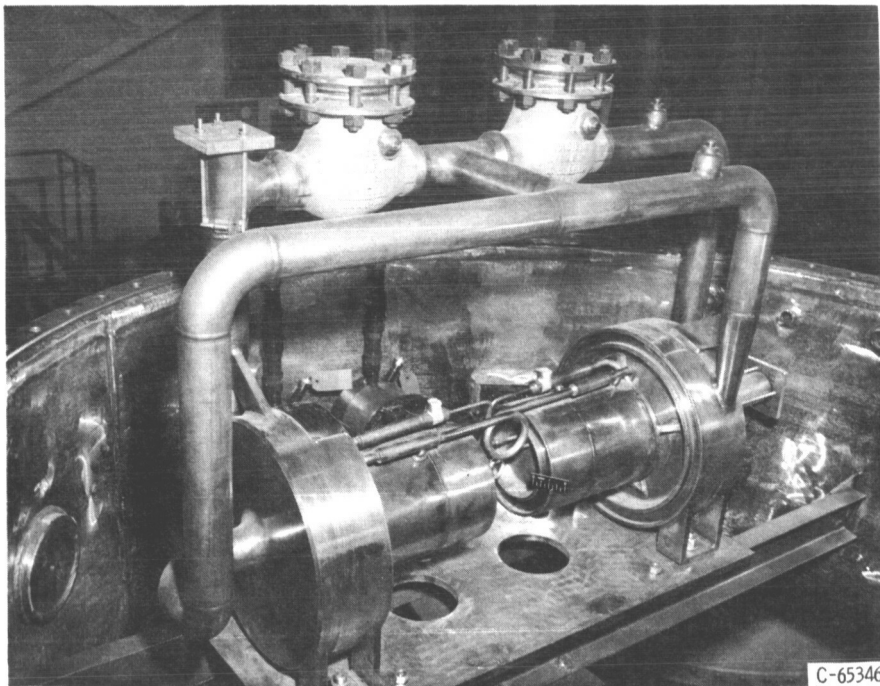
Figure 16. - Helium compressors.
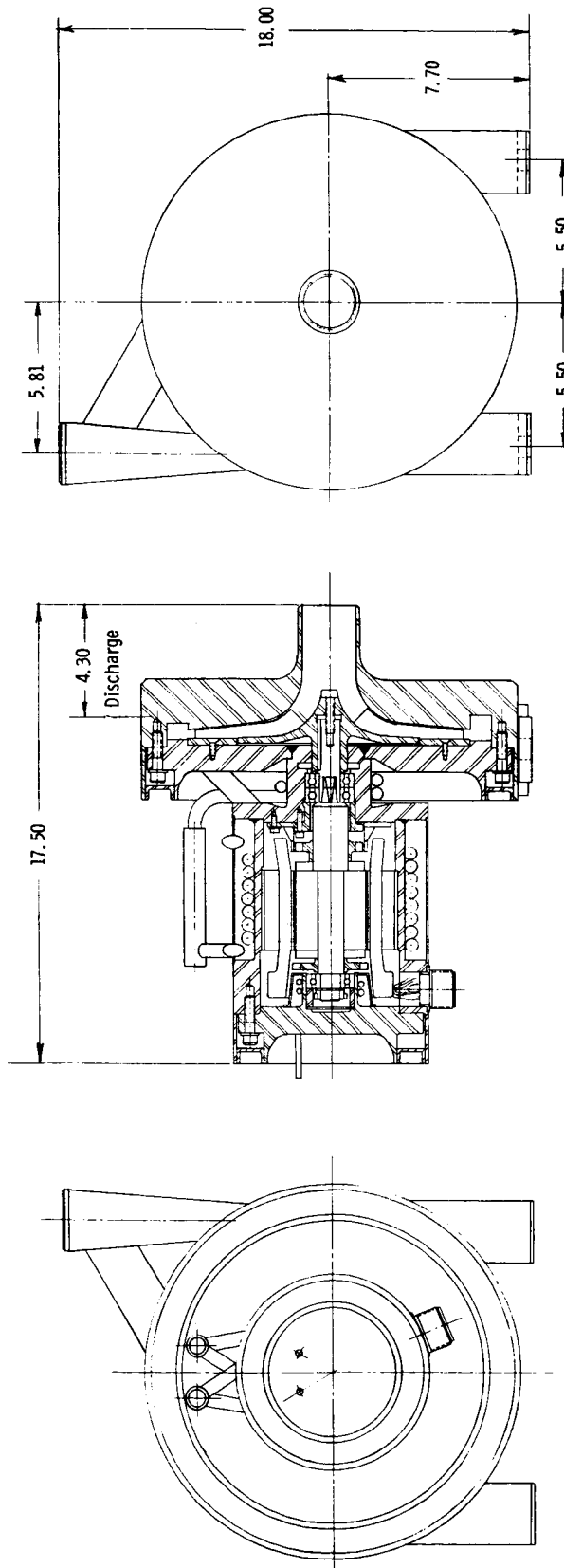
Figure 17. – Detailed view of compressor. (All dimensions are in inches.)

18.00

7.70

5.50

5.50

5.81

Discharge

4.30

17.50

Details of the close-coupled compressor and motor within a sealed common housing are shown in figure 17. The totally enclosed construction has eliminated external shaft extensions and resultant rotating shaft seals. The impeller, which is made of titanium alloy (Ti-6Al-4V), develops a maximum stress of 34 000 pounds per square inch at an operating speed of 22 000 rpm. This is well under the 0.2 percent yield point of 60 000 pounds per square inch for this alloy.

The motor and impeller shaft is supported by sealed ball bearings, which are lubricated with high-temperature nuclear-radiation-resistant grease. The motor and bearing mounts are cooled by water lines wrapped around the outside of the housings. This design separates the water from the helium by two separate barriers.

The impeller and motor housings are made of AISI type 300 stainless steel. The inlet and outlet connections are designed to withstand a thrust loading from the piping system of 750 pounds in any direction and a moment of 1000 foot-pounds in any direction.

The motor that drives the impeller is a 400-cycle, 3-phase, 440-volt induction motor. The power is brought in through a hermetically sealed electrical receptacle in the motor housing.

The performance ratings and characteristics of the compressors are as follows:

Service fluid . . . . Dry helium
Mass flow rate, lb/sec 0.24
Normal working pressure at inlet (first stage compressor), psia 200
Normal service fluid temperature at inlet (first stage compressor), $^\circ$F 265
Minimum pressure rise across both compressors at preceding
    conditions, psi 27
Design pressure at outlet, psig 250
First stage design fluid temperature at inlet, $^\circ$F 350
Normal cooling water flow, gal/min 6.5
Normal inlet cooling water temperature, $^\circ$F . . . . 65 to 68
Normal inlet cooling water pressure, psia . . . . 55 to 65
Design inlet cooling water pressure, psig 100
Maximum cooling water pressure drop (nozzle to nozzle), psi 3

Heat Exchanger, HX-103

The heat exchanger, which extracts the heat absorbed by the helium coolant, is a single-pass, bayonet-tube, gas-to-water unit. It was designed, fabricated, and pressure tested according to the procedure in reference 2. The all-welded unit is made of AISI type 304 stainless steel. Details of the heat exchanger are shown in figure 18. A photographic view is shown in figure 14(c).

Longitudinal grooves
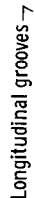
Partial view D-D showing
inner and outer tubes

2 (typical)

Partial view C-C with cap re-
moved showing tube bundle

Water outlet

Water inlet

Gas outlet

Gas inlet

$39\frac{1}{4}$

65

8

$4\frac{3}{8}$

$6\frac{5}{8}$

Figure 18. – Detailed drawing of heat exchanger. (All dimensions are in inches.)

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The requirement of double containment posed a special problem in selecting the type of heat exchanger to be used in this loop. The limited space available in the equipment tank required that the unit be small in size and simple in construction. These requirements ruled out arrangements such as a coupled two-heat exchanger system. The problem of providing a monitoring space between double barriers without hindering the transfer of heat was accomplished in the following manner.

Each of the 19 bayonet-tube units has a double wall. The outer tube was swaged onto the inner tube which had longitudinal grooves machined the full length of the tube on its outer surface (see fig. 18). The swaging provides good metal-to-metal contact for heat transfer across the wall between the grooves. The grooves provide a leakage path for either helium or water into a port which is common to all the tubes. This monitoring space is evacuated and sealed off prior to operation, and any increase in pressure resulting from a leak will be detected by a pressure transducer which is connected to the port.

The heat exchanger is designed to remove 230 kilowatts of heat at the following operating conditions:

Operating condition	Helium	Secondary water
Flow rate	0.24 lb/sec	21 gal/min
Inlet temperature, °F	1000	65 to 85
Outlet temperature, °F	265	140 to 160
Inlet pressure, psia	203	55 to 65
Pressure drop, psi	2.03	1.08

At a reduced heat load of **130 kilowatts, the heat exchanger** will have the following operating conditions:

Operating condition	Helium	Secondary water
Flow rate	0.24 lb/sec	21 gal/min
Inlet temperature, °F	577	65 to 85
Outlet temperature, °F	162	108 to 128
Inlet pressure, psia	177	55 to 65
Pressure drop, psi	2.03	1.08

In addition to being designed to operate at the preceding normal conditions, the heat exchanger was structurally **designed to withstand the following extreme conditions:**

Maximum water outlet temperature, °F 200

Minimum gas pressure, mm Hg absolute 1

Maximum gas inlet pressure, psig 250

Maximum water inlet pressure, psig 100

Maximum inlet gas temperature increase (7-sec transient condition), °F/sec 30

Maximum inlet gas temperature decrease (10-sec transient condition), °F/sec 20

The inlet and outlet connections are designed to withstand a thrust loading from the piping system of 750 pounds in any direction and a moment of 1000 foot-pounds in any direction.

Filter F-105

The helium filter unit consists of a housing with a glass-type filter element that will remove 99.97 percent of the particles 0.3 micron or larger from the helium coolant. The filter unit was designed, fabricated, and pressure tested according to the procedure in reference 2.

The filter housing is an all-welded unit except for a removable cover, which permits replacement of the filter element. The cover is a blind flange, bolted down with sixteen $1\frac{1}{8}$ inch bolts welded to the underside of the mating slip-on flange, which facilitates removal of the cover and filter element remotely. All housing material in contact with helium is AISI type 304 stainless steel. (A photograph of the filter is shown in figs. 14(a) and (b).)

The filter was designed to meet the following maximum conditions: a helium temperature of 1000° F and a helium pressure of 250 pounds per square inch gage. The maximum allowable nozzle-to-nozzle pressure drop was 0.4 pound per square inch.

Supply Tank T-106

The 0.4-cubic-foot supply tank provides a high-pressure supply of helium for pressure adjustment of the closed helium loop (see fig. 14(c)). It is constructed of 6-inch schedule 40 pipe and weld caps of AISI type 304 stainless steel. It was designed, fabricated, and pressure tested according to the methods in reference 2.

The tank was designed for a maximum pressure of 600 pounds per square inch and a maximum temperature of 400° F.

Surge Tank T-107

The surge tank, which has a capacity of 4.7 cubic feet, minimizes the pressure surges in the loop due to temperature and pressure fluctuations (see fig. 14(c)). It is constructed of 14-inch schedule 40 pipe and weld caps of AISI type 304 stainless steel. It was designed, fabricated, and pressure tested according to the procedure in reference 2. The tank was designed for the maximum conditions given in the preceding section.

Metering Tank T-109

The 45-cubic-inch metering tank is used to introduce additional high-pressure gas to the helium loop from the supply tank to top off the system to the desired pressure (see fig. 14(c)). The gas will be brought in through solenoid valve V-109, which isolates the metering tank from the supply tank, and V-110 and V-114, which isolate the main helium loop from the supply and metering tanks. The inlet side of valve V-114 is towards the main helium loop to prevent a discharge of gas from this system in the event of an accidental rupture of the piping external to the equipment tank. The metering tank is designed according to the procedure in reference 2 and is constructed of 3-inch schedule 40 pipe and weld caps of AISI type 304 stainless steel. The tank was designed for the same maximum conditions as those for the supply tank T-106.

Main and Standby Water Pumps P-402 and P-401

Centrifugal pumps circulate cooling water from the quadrant or canal to the loop during transport to the hot lab and for emergencies caused by loss of water coolant. They are identical, electrically driven, hermetically sealed pumps. A photograph of the pumps is shown in figure 19.

At the required flow of 27.5 gallons per minute needed to cool the heat exchanger

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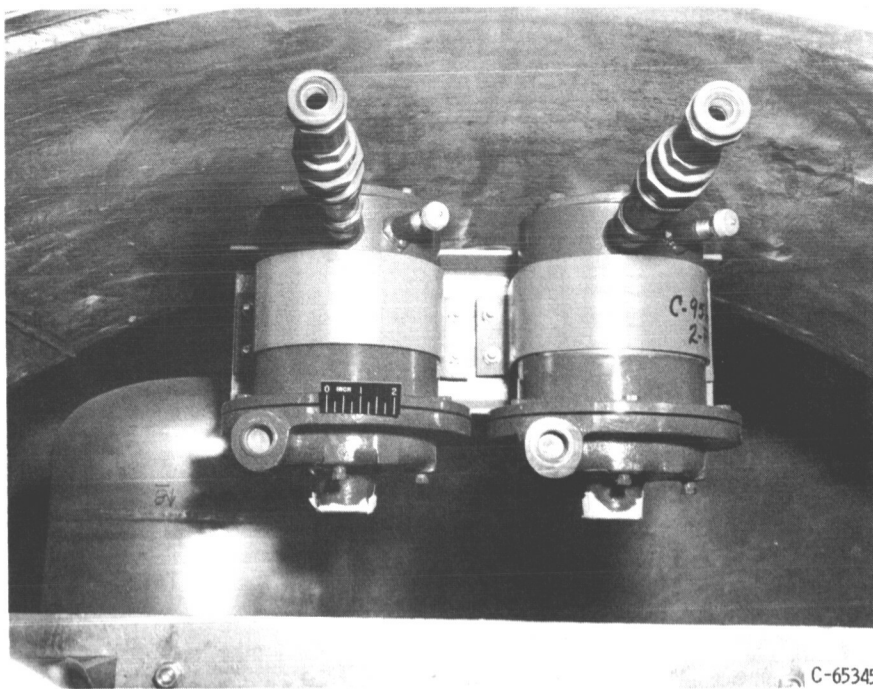
Figure 19. - Quadrant water pumps.

and compressors, each water pump has a total dynamic heat of 29 pounds per square inch, which is more than adequate for the total pressure drop of the heat exchanger, compressors, and associated piping.

The normal operating conditions are as follows:

Flow, gal/min 27.5
Dynamic head, psi 29
Net posiiive suction head, psi 10
Outlet pressure, psig 39
Inlet temperature, ^{O}F . . . . 65 to 85
Ambient air temperature, ^{O}F 175

The pumps were designed and pressure tested according to the procedure in reference 2 for a working pressure of 150 pounds per square inch gage and an inlet temperature of 85° F. All metal parts in contact with the water are made of AISI type 300 series stainless steel. The bearings are made of type P carbon graphite and require no external lubrication. The motors are totally enclosed and operate on 440-volt, 3-phase, 60-cycle power. The insulation is class H, American Institute of Electrical Engineers standard 1.

Sump Pump P-501

The sump pump, shown in figure 20, is a two-stage centrifugal pump mounted vertically with the inlet in the sump of the equipment tank. The sump is located to collect any water leakage into the tank or any leakage from the loop water systems. The pump will deliver 10 gallons of water per minute at a total dynamic head of 19 pounds per square inch. The motor is totally enclosed and rated at 1 horsepower, 440 volts, 3 phase, and 60 cps.

Main Helium Throttling Valve V-101

The main helium throttling valve, V-101, controls the flow of coolant to the test section, thereby controlling the temperatures of the test specimen and outlet gas (see fig. 14(a)). It is a custom-built 2-inch gate valve with an equal percentage plug. All parts in contact with the service fluid are made of stainless steel.

The valve is actuated by an integral electrohydrualic system and is capable of a full-range stroking time of 5 seconds. The spring-loaded stem will drive the valve to the full-open position in the event of a power or signal failure. The valve position is
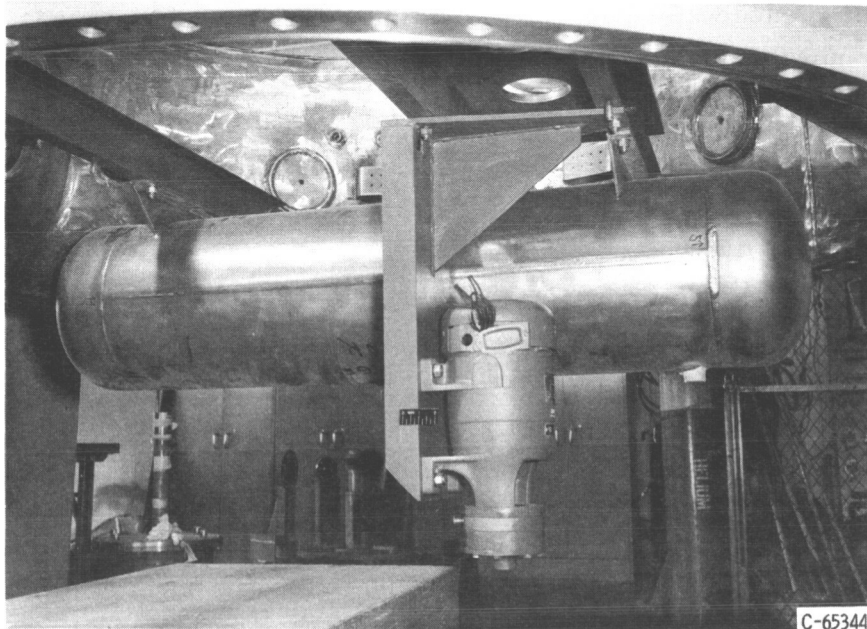
Figure 20. - Sump pump.

controlled by an electronic controller that can be set for automatic or manual operation. A linear variable differential transformer coupled to the stem gives valve position indications.

The hydraulic fluid used in the system is cooled by a small heat exchanger using secondary coolant water. According to the manufacturer's tests, the oil should suffer no radiation damage in a gamma radiation field of 600 rads per hour at an expected operating temperature of less than 150° F for 2500 hours.

Design conditions are as follows:

Flow, lb/sec . . . . Dependent upon desired temperatures of test specimen and exit gas, 0.24 max.

Helium temperature, ^{O}F 360

Helium pressure at inlet, psia 227

Maximum pressure drop with valve open and a flow of 0.24 lb/sec, psi 1.0

Ambient air temperature, ^{O}F 175

The valve was structurally designed for the following maximum conditions:

Maximum helium temperature, ^{O}F 400

Maximum helium pressure, psig 250

Maximum inlet-to-outlet differential pressure with valve closed, psi 27

Element Bypass Throttling Valve V-102

The bypass throttling valve (V-102) in the 1-inch bypass line is used in conjunction with the main throttle valve (V-101) to regulate the flow of helium to the test section and the bypass line (see fig. 14(a)).

It is also a custom-built 1-inch gate valve with an equal percentage plug and is similar in construction to V-101. The valve position of V-102 is set by a manual controller.

The operating conditions for this valve are similar to those for V-101, except that the maximum flow is 0.18 pound per second. The pressure drop across this valve is 10 pounds per square inch for the conditions of maximum flow (0.18 lb/sec) and the valve full open.

Valves and Piping

The design requirements for the valves in the loop systems are presented in table II, and the same information for the piping is presented in table III.

Helium piping. - In order to ensure the integrity of the piping and components of the helium system, prime welds were subjected to dye penetrant and/or radiographic examination. The piping and components were also leak checked. The total allowable leak rate, as determined by a helium mass spectrometer leak detector, is less than 1×10^{-7} standard cubic centimeter per second when pressurized with helium to 1 atmosphere differential.

A complete analysis was performed to determine the pressure drop in this system. These results are given in appendix C and can be summarized as follows: The total pressure drop throughout this system ranged from 4.13 to 4.95 pounds per square inch for helium flow rates through the test section of 0.6 to 0.24 pound per second. These values were calculated for the case when the loop is removing 130 kilowatts of heat. When the loop is operating at 230 kilowatts, the pressure drop ranges from 4.33 to 5.15 pounds per square inch for gas flow rates through the test section of 0.6 to 0.24 pound per second.

The analysis used to compute the thermal stresses of the piping in this system is described in reference 4 and is based on the hot modulus of elasticity and the assumption of square corners. Results of these computations are not presented. In general, stresses due to pressure were found to be quite low. For most cases the thermal stresses dictate the actual routing of the piping in the main loop. The magnitude of the thermal stresses, however, were well within the design limitations.

Water system piping. - The major water systems inside the equipment tank are designed for a pressure of 100 pounds per square inch gage and a temperature of 200° F.

TABLE II. - VALVE SCHEDULE

Valve (a)	Type	Application	Pipe size, in.	Working fluid	Normal service fluid temperature, °F	Normal working pressure, psia	Maximum design service fluid temperature, °F	Maximum design working pressure, psig	Rated flow	Inspection procedure (b)	Valve-body material AISI stainless steel type
Helium system											
V-101	Motor, NO	Throttle	2	Helium	360	227	400	250	0.24 lb/sec	DP, R, V, D, ALV, HP, HLW, FT	316
V-102	Motor, NC	Throttle	1		360	227		250	.18 lb/sec	DP, R, V, D, ALV, HP, HLW, FT	316
V-105	Check, swing	Bypass	2		265	227		250	.24 lb/sec	ALV, FT, DP, R, V, HP, HLW	304
V-106	Check, swing	Bypass	2		360	227		250	.24 lb/sec	ALV, FT, DP, R, V, HP, HLW	304
V-107	Globe-bellows seal	Shutoff	1/2		85	500		600	------	V, HP, HLW, ALV	316
V-109	Solenoid, NC	Shutoff	1/2		255	500		600	------	DP, R, V, D, HP, HLW, ALV, FT	304
V-110	Solenoid, NC	Shutoff	1/2		255	500		600	------	DP, R, V, D, HP, HLW, ALV, FT	304
V-111	Solenoid, NC	Shutoff	1/2		255	200		250	------	DP, R, V, D, HP, HLW, ALV, FT	304
V-112	Globe-bellows seal	Shutoff	1/2		85	200		250	------	V, HP, HLW, ALV	316
V-113	Safety-relief	Pressure relief	1		360	227	300	2000	------	V, HP	303
V-114	Solenoid, NC	Shutoff	1/2		255	200		250	------	DP, R, V, HP, HLW, ALV, FT	18-8
Primary water system											
V-201	Quick disconnect	Inlet	1½	Water	130	160	200	150	------	V, HP	316
V-202	Quick disconnect	Outlet	1½		150	160	200	150	------	V, HP	316
V-204	Solenoid, NC	Shutoff	3/4		130	160	500	1500	18 gal/min	V, HP	316
Cooling tower water system											
V-301	Solenoid, NO	Shutoff	1¼	Water	85	65	200	100	25 gal/min	V, D, HP, WLWV, ΔP	316
V-302	Check	Flow check	1½		85	65	200	100	------	V, HP	
V-306	Globe	Throttle	1½		130	65	200	100	------	V, HP	
V-307	Safety relief	Pressure relief	1/2		340	116	450	2000	6 gal/min at 1 percent overpressure	V, HP	
V-308	Solenoid, NO	Shutoff	1¼		130	65	200	100	25 gal/min	V, D, HP, WLWV. ΔP	
V-318	Quick disconnect	Inlet	2		85	65	200	100	------	V, HP	
V-319	Quick disconnect	Outlet	2		130	65	200	100	------	V, HP	
V-320	Check	Flow check	1½		130	65	200	100	------	V, HP	

Quadrant water system

V-402	Check	Flow check	$1\frac{1}{2}$	Water	85	65	200	100	-------	V, HP	316
V-403	Solenoid, NO	Shutoff	$1\frac{1}{4}$	→	130	→	→	→	25 gal/min	V, D, HP, WLWV, ΔP	316
V-405	Check	Flow check	$1\frac{1}{2}$	→	85	→	→	→	-------	V, HP	316
V-406	Quick disconnect	Hot lab testing	$1\frac{1}{2}$	→	85	→	→	→	-------	V, HP	303
V-407	Quick disconnect	Hot lab testing	$1\frac{1}{2}$	→	85	→	→	→	-------	V, HP	303

Equipment tank systems

V-501	Check	Flow check	1	Water	85	25	100	25	-------	V, HP	316
V-502	Globe	Shutoff	1/2	Air	→	25	→	25	-------	V, HP	→
V-503	Globe	Shutoff	1/2	Air		25		25	-------	V, HP	
V-504	Globe-bellows seal	Static connection	1/2	Helium	→	15	→	250	-------	V, HP, HLW, ALV	
V-505	Globe-bellows seal	Static connection	1/2	Vacuum		0		250	-------	V, HP, HLW, ALV	
V-507	Solenoid, NC	Shutoff	$1\frac{1}{2}$	Water	→	25	200	100	-------	V, D, HP, WLWV, ΔP	
V-508	Quick disconnect	Outlet	$1\frac{1}{2}$	Water		25	200	100	-------	V, HP	
V-509	Globe	Shutoff	1/2	Water		25	100	25	-------	V, HP	
V-510	Quick disconnect	Sump line	1	Water	→	25	100	25	-------	V, HP	
V-511	Globe-bellows seal	Static gas and helium purge	1/2	Helium	170	200	400	250	-------	V, HP, HLW, ALV	
V-512	Check	Flow check	1	Air and water	170	25	500	150	-------	V, HP, WLWV	
V-513	Safety relief	Pressure relief	1	Air	170	25	180	150	-------	V, HP, FT	
V-630	Globe	Shutoff	1/2	Helium	85	200	400	6000	-------	V, HP, HLW, ALV	303 (low Mo)
V-631	Globe	Shutoff	1/2	Helium	85	500	400	6000	-------	V, HP, HLW, ALV	303 (low Mo)
V-632	Globe	Shutoff	1/2	Air	85	25	400	6000	-------	V, HP	303 (low Mo)

[a] All motor and solenoid valves operate on 115 V, 60-cycle, alternating current. NO, normally open; NC, normally closed.

[b] DP, dye penetrant examination of all welds; R, radiographic examination of all welds; V, visual examination; D, dielectric test, 1000 V; HP, hydro-static pressure test; HLW, external helium leak test; ALV, internal air or nitrogen leak test; FT, function test; WLWV, water leak test - internal and external; ΔP, pressure drop test.

TABLE III. - PIPING SYSTEMS

System	Rating		Material	Joint	Fitting	Inspection and test procedure
	Temperature, °F	Pressure, psig				
Helium	400 and 1000	250 and 600	300 series stainless-steel schedule 40 pipe	2-in. and larger butt weld; less than 2-in. socket weld	2-in. and larger schedule 40, 300 series stainless-steel butt weld; less than 2-in. 3000-lb 300 series stainless-steel socket weld	Hydrostatic or pneumatic test, dye penetrant and radiograph all welds, helium leak test
Vacuum and monitoring	400	250	300 series stainless-steel tubing	Socket weld	Cajon tube fittings	Hydrostatic or pneumatic test, dye penetrant and radiograph all welds, helium leak test
Cooling tower and quadrant water	200	100	300 series stainless-steel schedule 40 pipe	Socket weld; screwed and seal welded at valves and equipment	2-in. and larger schedule 40, 300 series stainless-steel butt weld; less than 2-in. 3000-lb 300 series stainless-steel socket weld	Hydrostatic test
Primary water	200	200	300 series stainless-steel tubing	Socket weld	Cajon tube fittings	Hydrostatic test, dye penetrant and radiograph all welds, helium leak test
Miscellaneous service	250	25	300 series stainless-steel schedule 40	Socket weld	3000-lb 300 series stainless-steel socket weld	Hydrostatic test

Therefore, the pressure stresses, the thermal expansion stresses, and the stresses induced by the thermal expansion of the heat exchanger are negligible.

Flexible lines are used to interconnect the loop systems with the reactor system. Primary water supply and return lines (for nuclear shield) and the hot drain line are $1\frac{1}{2}$-inch inside diameter, 35-foot-long, single-braided flexible metal hoses of AISI type 321 stainless steel. These lines will operate at a maximum pressure of 145 pounds per square inch gage and a maximum temperature of 150° F. The hot drain line will operate at a maximum temperature of 160° F. The burst pressure of the hose is 2450 pounds per square inch. The socket halves of the quick-disconnect couplings are welded to both ends of the hoses so that they can be connected to the water systems at the quadrant wall and the equipment tank.

The secondary coolant water supply and return lines are 2-inch inside diameter, 35-foot-long, single-braided flexible metal hoses of AISI type 321 stainless steel. These lines will operate at a maximum pressure of 50 pounds per square inch gage and a maximum temperature of 160° F. The burst pressure of the hose is 2000 pounds per square inch. The hoses are flanged on one end so that they can be connected to the secondary coolant water supply and return lines at the quadrant wall. The socket halves of the quick-disconnect couplings are connected to the equipment tank.

CONTROL AND INSTRUMENTATION

The control, monitoring, and data recording of the loop is handled completely from the control console. The instrumentation and control points of the loop superimposed on the system flow diagram are shown schematically in figure 8. During a test, the control console is connected to the equipment tank through the operate junction box, located on the edge of quadrant A. During transport to the hot lab, the interconnection between the tank and console is through the transport junction box, located between the reactor containment vessel and the hot lab. These locations are shown in figure 2.

Equipment Console

Details of the console associated with the control of the loop are shown in figures 21(a) and (b). The graphic panel (fig. 21(b)), which is located at the top center of the main control console, presents a simplified version of the flow circuits to the operator for quick reference. There are two indicating lamps for each valve or other piece of equipment so that misinterpretation because of lamp burnout can be avoided.

Lens
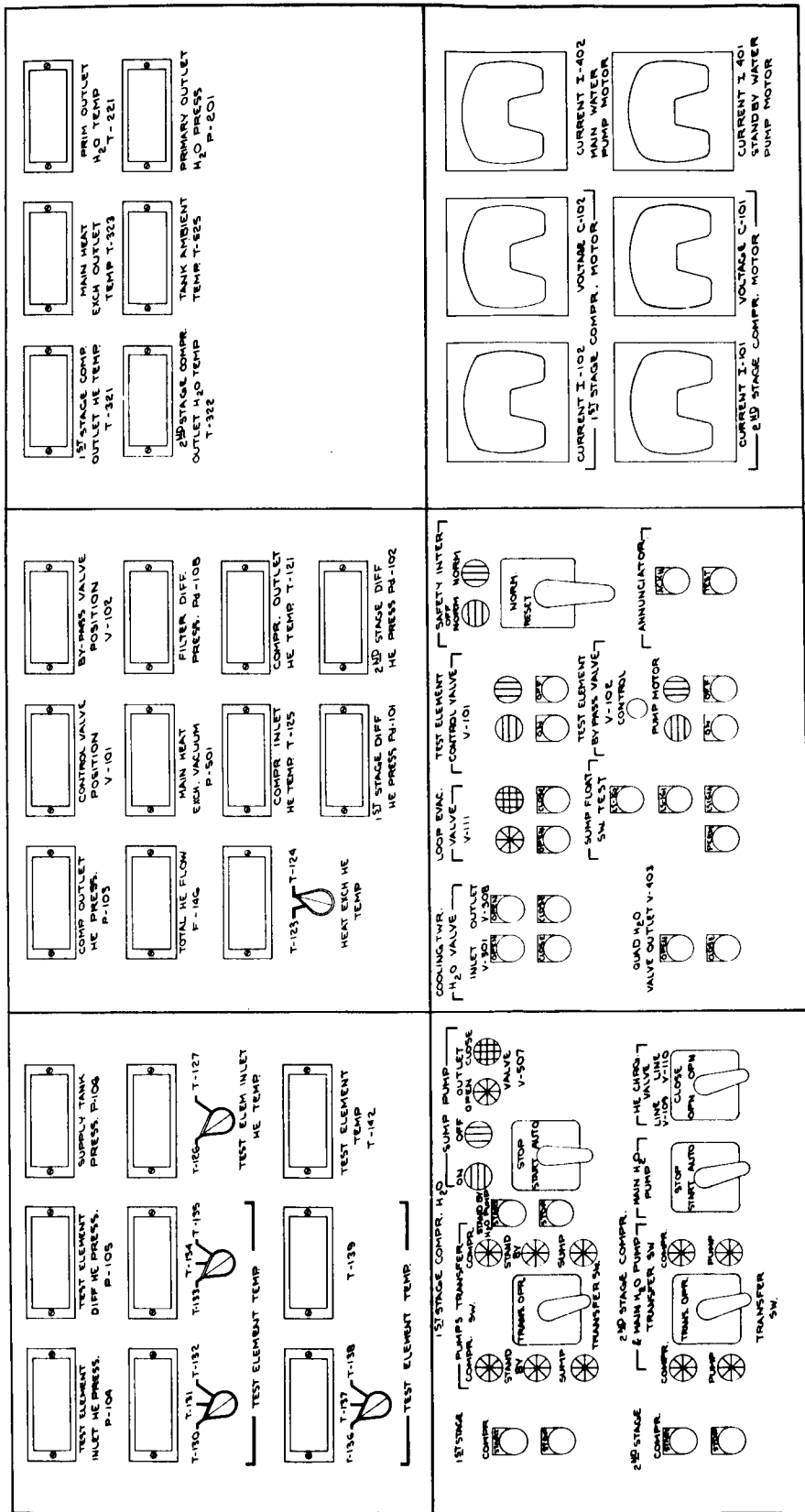
⊛ White   ⊕ Blue   ⊖ Red   ⊖ Green
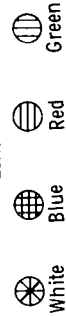
(a) Center section.

Figure 21. – Control console.
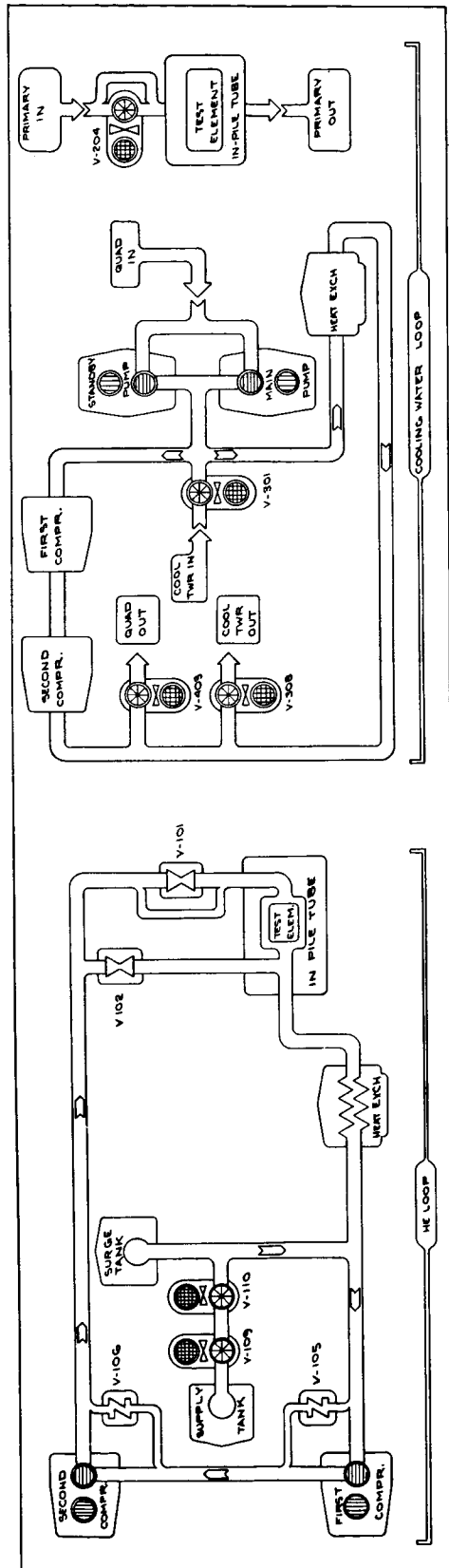
Lens

White Blue Red Green

(b) Graphic panel.

Figure 21. - Concluded.

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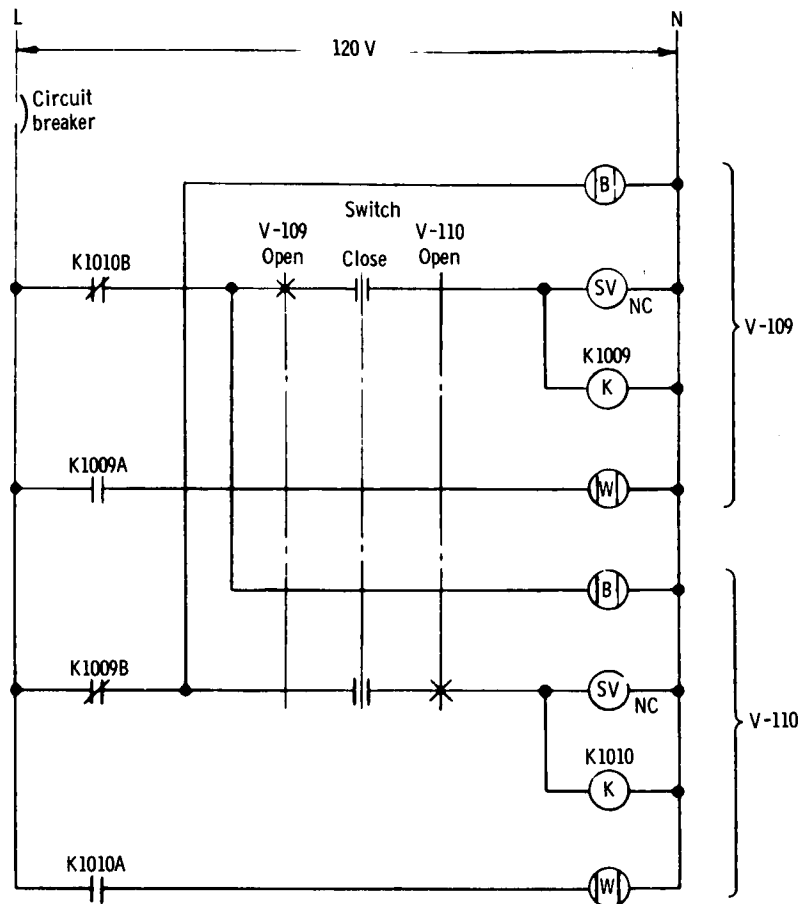
(a) Helium loop charge valves V-109 and V-110.

(SV) Solenoid valve	(B) Blue lamp	(R) Red lamp
(K) Relay	(W) White lamp	NC Normally closed
(M) Motor starter coil	(G) Green lamp	NO Normally open
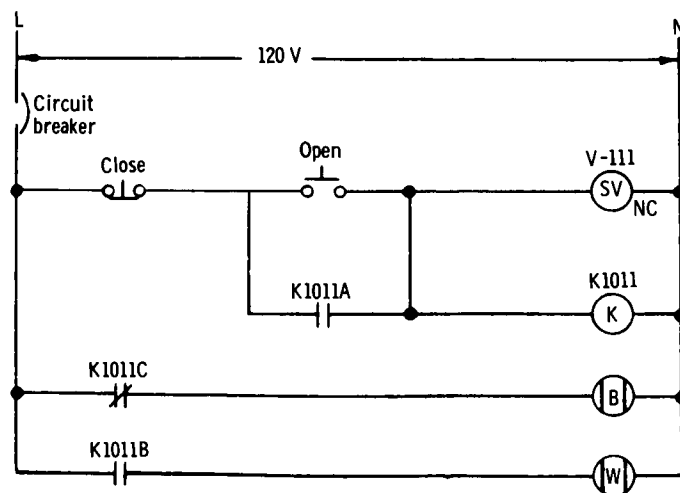
(b) Loop evacuation valve V-111.

Figure 22. – Schematic of helium valve controls.

(c) Test element helium control valve V-101.

Figure 22. – Concluded.

In general, the operational modes for each solenoid valve, relay contact, or other component was chosen so that in case of power interruption, the components would be in the safest position (either open or closed). For example, all the annunciator positions, which alarm from relay contacts, initiate an alarm in the event of a power loss to the relay coils.

Helium valves. - The helium coolant system on the graphic panel shows valves V-109 and V-110. The function of these valves is to top off the helium system pressure. These two valves are normally closed (with power off), and are interlocked electrically, as shown in figure 22(a). They are operable one at a time so that the topping process is accomplished through the action of alternately opening and closing one valve and then the other. This interlocking prevents the inadvertent emptying of the supply tank into the system. In the power-off, or fail-safe condition, the helium in the supply tank is contained by the two closed valves.

Valves V-105 and V-106, shown on the graphic panel, are the mechanical check valves that force the helium to bypass a compressor when it is not in use.

Valves V-101 and V-102 are remotely controlled throttling valves. The schematic diagram presented in figure 22(c) for V-101 is typical for both. The valves are unique in that the valve and its hydraulic system packaged as a unit and need only electrical control signals and power as inputs. An electrical power failure or the release of relay contact K 1039E, which is operated by any instrument safety channel, stops the hydraulic pump motor of each control valve, and the valves then return to their fail-safe position by mechanical spring action (V-101 opens and V-102 closes). For the V-102 circuit, the controller is replaced by the potentiometer circuit (see fig. 22).

Water valves. - The control circuitry for valves V-403, V-301, V-308, and V-507 is shown in figure 23. Valve V-403 is normally open so that the quadrant water can be used as a backup to the secondary cooling water supply. It is kept closed during normal operation to prevent dumping secondary cooling water into the quadrant. The valve is electrically interlocked with the main and standby pumps. This interlocking allows it to be closed when the pumps are not running and be automatically opened if either pump is energized. In addition, V-403 can be manually opened by a pushbutton control. Whenever V-403 is open, the annunciator receives an alarm signal from a limit switch mounted on the stem of V-403.

Secondary cooling water inlet and outlet valves, V-301 and V-308, respectively, have similar control circuits (see fig. 23). Both valves are normally open to their fail-safe position to provide cooling in case of either selective or complete electric power failure. There are three ways in which these valves may be closed: (1) in backup action, by either quadrant pump starting, (2) through the highest level containment-tank float-switch, LS-162, and (3) by the manual pushbutton station at the control console. Both valves utilize electrical holding circuits when closed. Releasing action of the valves is

Figure 23. - Schematic of water-valve controls.
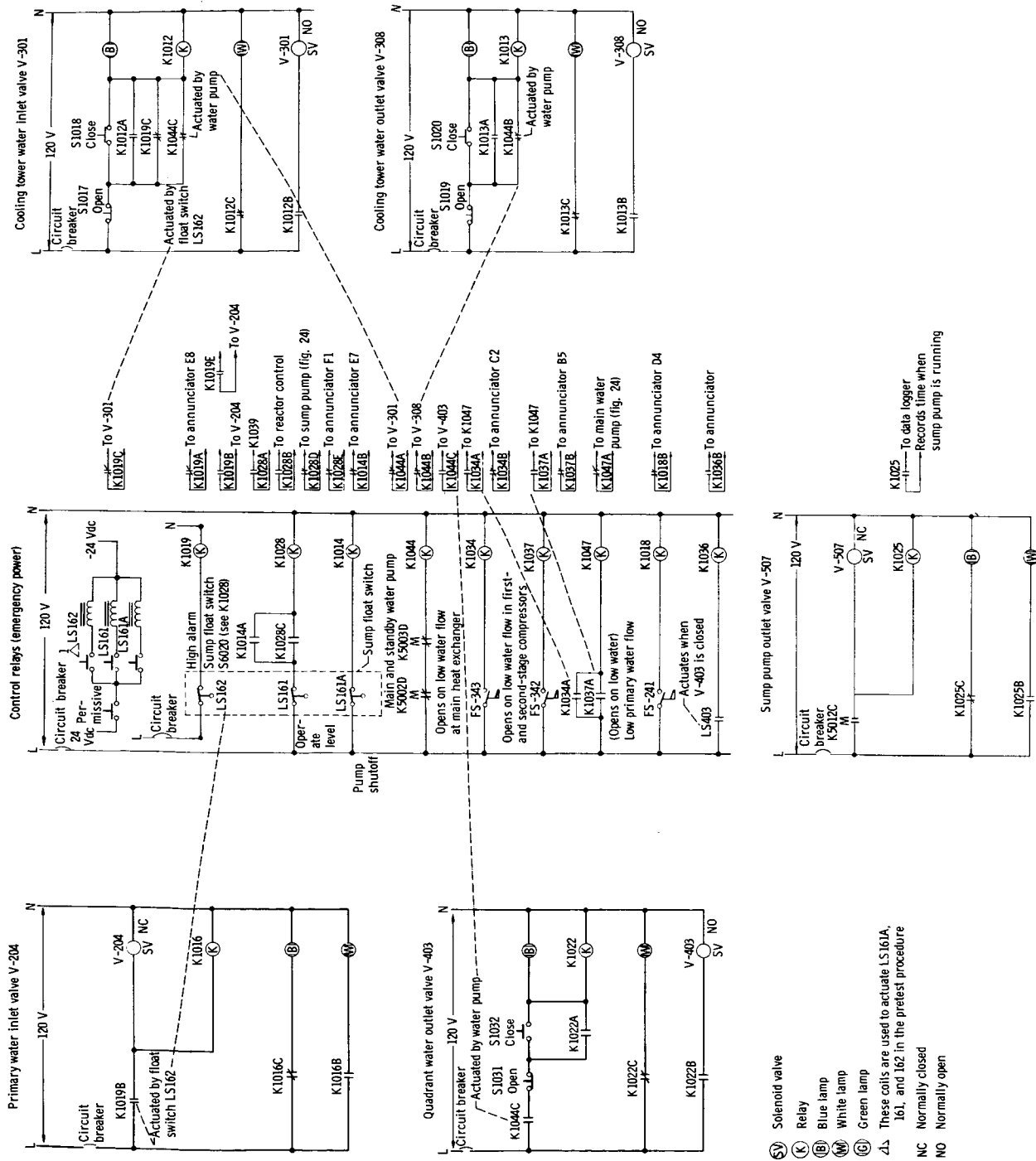
limited (other than power failure) to their respective valve pushbuttons.

The sump discharge valve, V-507, opens automatically whenever the sump pump starts. Valve V-507 closes in case of power failure (fail-safe position).
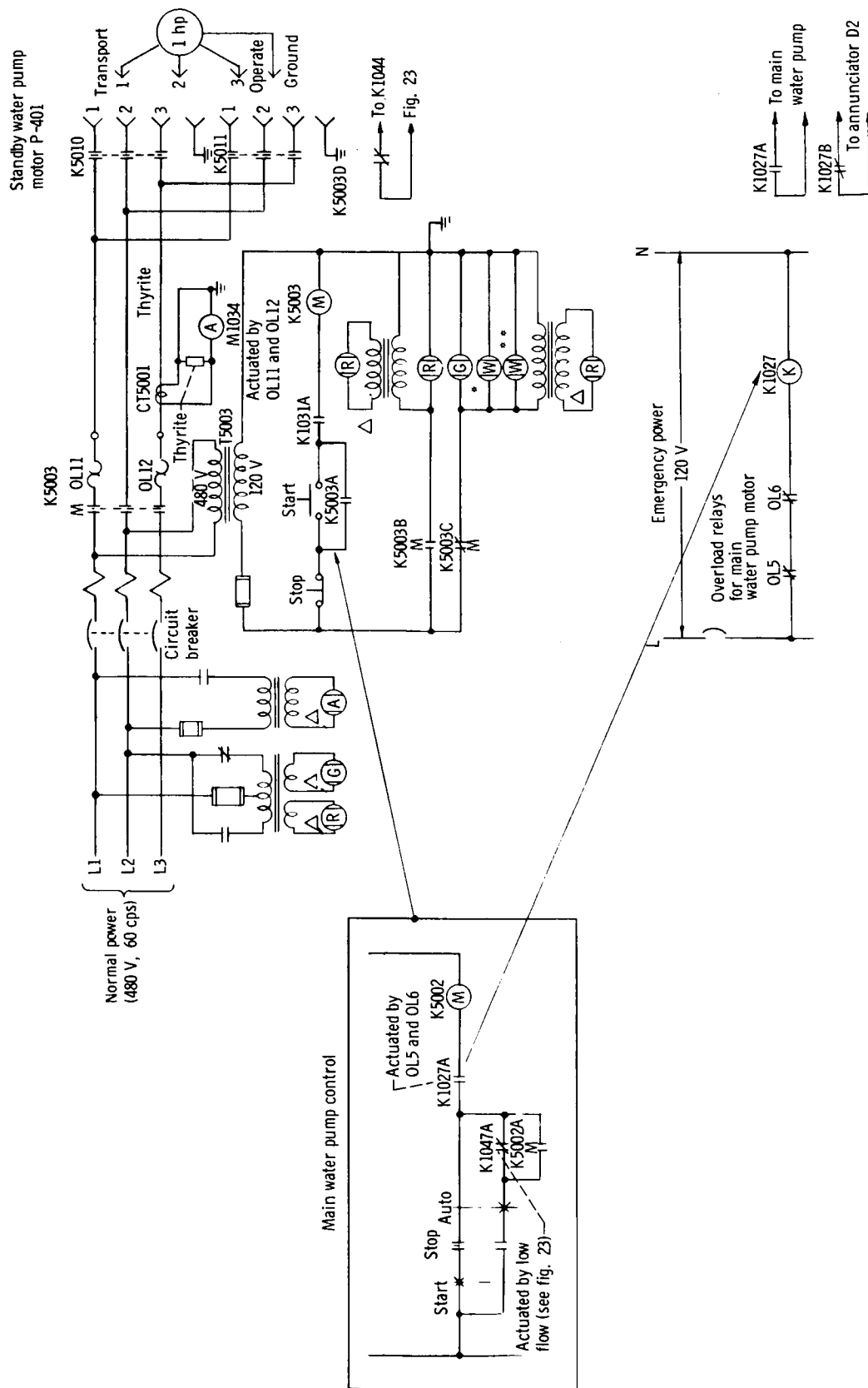
Compressor control center. - Because of the duplicate units, the circuit for only one compressor (the first stage) is shown in figure 24(a). Each M-G set can be controlled from its compressor control center located near the sets in the reactor building basement or from the primary control point on the control console (see fig. 21(a), p. 42). Locks are provided at the unattended location of the compressor control centers and motor control centers for critical items, such as breakers and start-stop buttons, to prevent accidental interruption of compressor operation.

Motor control center. - Figure 24(b) contains circuit details on the motor control center. The main water pump has an automatic start-stop switch. It should be noted that The automatic position of the switch provides for automatic circulation of quadrant water through the secondary system if both the heat-exchanger water flow and the first- and second-stage compressor cooling water flows are low. The standby water pump does not have automatic startup as does the main water pump.

The sump pump also has an automatic start-stop switch. It should be noted that switch LS-161 starts the sump pump, and switch LS-161A turns the pump off. A third switch, LS-162, is energized by the emergency power lines to give a backup alarm signal. Putting the switch in the start position provides for the direct manual operation of the sump pump. The purpose of switch LS-162 is to close both the primary water valve, V-204, and the secondary water valve, V-301 (see figs. 8 and 23).

Operate-transport transfer switches. - The transfer switch and its interlocks shown in figure 24(c) permit the loop control to be switched from the operate cables to the transport cables and vice versa. The compressors and the water pumps are duplicated to provide emergency backup and continuity in cooling during switchover. To do this, it is necessary to have the transfer switches in two independent groupings with each grouping having its own independent control switch at the console. For simplicity, the schematic for only one grouping, including the transfer switches, the first-stage compressor, the standby water pump, and the sump pump, is shown in figure 24. This group gets its power from the commercial (normal) power lines. The second-stage compressor and the main water pump, which are connected to the emergency power lines, make up the second transfer switch combination. One compressor continues to operate during the disconnection of the operate cables and reconnection to the transport cables. For personnel and equipment safety during coupling and uncoupling of cables, each transfer switch energizes warning lamps at each cable junction box to indicate when the 480-volt lines are deenergized.

Helium temperature controller. - A block diagram of the test specimen exit helium temperature control system is shown in figure 22(c). When T-129 senses a deviation

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NOTE: Transfer switch is mechanically held, remote-controlled switch. Power contacts of compressor transfer switch is toggled to the operate position by solenoid L5004 and to transport side by solenoid L5005. Normally closed auxiliary contacts L5004 and L5005 are mechanically opened when their respective solenoids L5004 and L5005 pull home. Solenoids of the two remaining transfer switches are used only to release their respective mechanically held relays.

First-stage compressor motor C-101

20 hp, 440 V, 400 cps

Operate

Transport

Transfer switch (see note)

L5004

L5005

A   Amber lamp   K   Relay
AM   Ammeter   M   Motor starter coil
B   Blue lamp   Sol Solenoid
G   Green lamp   VM   Voltmeter
                       W   White lamp

All pushbuttons, control switches, indicating lights and meters located in motor control center or compressor control center unless other wise indicated:

△ Indicator lights and meters located in motor control center or compressor control center
* Indicator lights located in operate junction box
** Indicator lights located in transport junction box

Frequency meter M3

Normal power L1 L2 L3 (480 V, 60 cpsl)

Circuit breakers

Exciter regulator

(a) First-stage compressor; 400-cycle motor-generator set.

Figure 24. – Schematic of motor controls. (All control power is 120-V ac.)

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(b) Main and standby water pump controls.

Figure 24. - Continued.
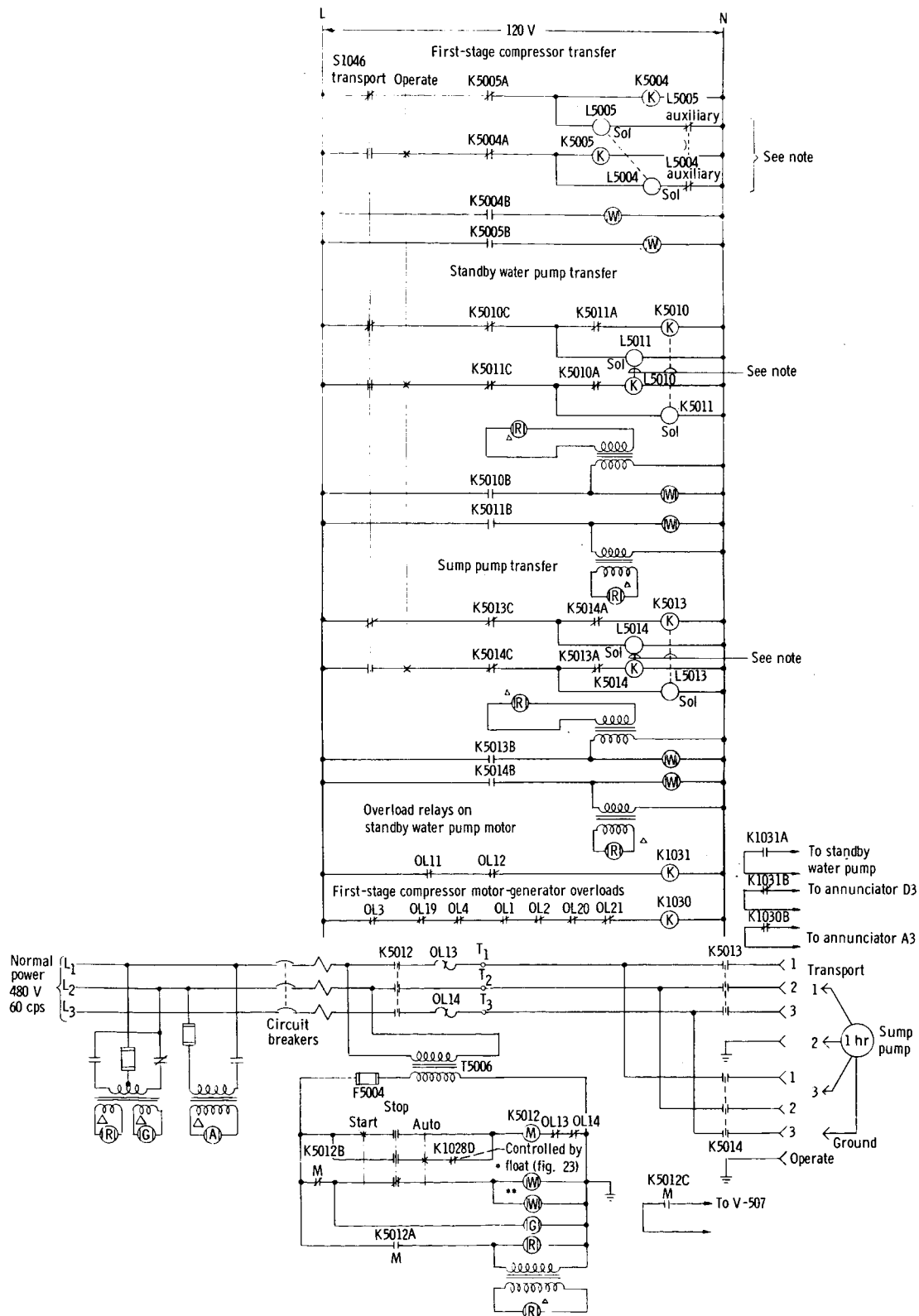
(c) Control relays (normal power).

Figure 24. – Concluded.

TABLE IV. - INSTRUMENTATION, ALARM, AND SAFETY ACTION TABLE

Variable	Transducer			Readout instrument[b]	Normal reading	Set point	Action	Annunciator position
	Designation	Type[a]	Range					
First-stage compressor differential pressure	[c]Pd-101	UPS	0 to 15 psi	ACM	13.5 psi	8 psi	Alarm (low)	A4
Second-stage compressor differential pressure	[c]Pd-102	UPS	0 to 15 psi	ACM	13.5 psi	8 psi	Alarm (low)	B4
Second-stage compressor outlet pressure	[c]P-103	UPS	0 to 250 psia	ACM	Test dependent	Test dependent	Alarm (high) Alarm (low)	F2 F3
Test specimen inlet helium pressure	P-104	UPS	0 to 250 psia	ACM	Test dependent	Test dependent	---------------	------
Test specimen differential helium pressure	[c]Pd-105	UPS	0 to 20 psi	ACM	Test dependent	Test dependent	Alarm (low) Alarm (high)	E3 E6
Helium supply tank pressure	P-106	UPS	0 to 700 psia	ACM	500 psia	--------------	---------------	------
Inpile tube inlet helium pressure	[c]P-107	UPS	0 to 250 psia	RSBP	179 psia	250 psia 150 psia 125 psia	Safety (1)[d] Alarm (low) Safety (1)	A1 C1 A1
Filter differential pressure	[c]Pd-108	UPS	0 to 1 psi	ACM	0.4 psi	0.75 psi	Alarm (high)	F5
Total helium flow	[c]F-146	VTFT and UPS	0 to 0.3 lb/sec	ACM	0.24 lb/sec	0.16 lb/sec	Alarm (low)	A8
Test specimen flow	[c]F-147	VTFT and UPS	0 to 0.3 lb/sec	RSBP	Test dependent	Test dependent Test dependent 0.30 lb/sec	Safety (1) Alarm (low) Safety (1)	A1 B1 A1
Test specimen flow	F-147A	VTFT and UPS	0 to 0.3 lb/sec	RSBP	Test dependent	Test dependent Test dependent 0.30 lb/sec	Safety (1) Alarm (low) Safety (1)	A1 F7 A1
Second stage compressor outlet temperature	[c]T-121	C-A	50° to 500° F	ACM	225° F	--------------	---------------	------
Heat exchanger inlet temperature	[c]T-123 [c]T-124	C-A C-A	50° to 1100° F 50° to 1100° F	ACM ACM	Test dependent Test dependent	1000° F 1000° F	Alarm (high) Alarm (high)	C8 C8
First-stage compressor inlet temperature	[c]T-125	C-A	50° to 500° F	ACM	Test dependent	300° F	Alarm (high)	A7
Test specimen inlet temperature	[c]T-126 [c]T-127	C-A C-A	50° to 500° F 50° to 500° F	ACM ACM	Test dependent Test dependent	350° F 350° F	Alarm (high) Alarm (high)	E4 E4
Test specimen inlet temperature	T-140	C-A	50° to 500° F	Data logger	Test dependent	--------------	---------------	------
Test specimen exit gas temperature	[c]T-128	C-A	0° to 1000° F	RSBP	Data logger	Test dependent	Alarm (high) Safety (2)	D1 A1
Test specimen exit gas temperature	[c]T-128A	C-A	0° to 1000° F	RSBP	Data logger	Test dependent	Alarm (high) Safety (2)	F6 A1
Test specimen exit gas temperature	[c]T-129	C-A	0° to 1000° F	RSBP	Data logger	Test dependent	Alarm (high)	A5
Test specimen plate temperature	T-130 to [c]T-139	P-PR	50° to 3000° F	ACM	Data logger	Test dependent	Alarm (high)	E5
Test specimen plate temperature	[c]T-142	C-A	50° to 2500° F	ACM	Data logger	Test dependent	Alarm (high)	E5
Filter radiation	R-151	Roentgen rate meter	0 to 50 000 R/min	Meter relay	-------------	Undetermined	Alarm (high)	F4

[a]C-A, Chromel-Alumel thermocouple; P-PR, platinum - platinum 13 percent rhodium thermocouple; UPS, unbonded strain gage pressure sensor; VTFT, Venturi-type flow tube.

[b]ACM, amplifier and control meter; ASCR, amplifier and strip-chart recorder; RSBP, recording self-balancing potentiometer.

[c]These instrument channels are also read out by data logger.

[d]Type of safety action: safety (1), Automatic reactor slow scram; safety (2), automatic reactor fast reverse; safety (3), automatic reactor slow setback.

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TABLE IV. – Continued. INSTRUMENTATION, ALARM, AND SAFETY ACTION TABLE

Variable	Transducer			Readout instrument[b]	Normal reading	Set point	Action	Annunciator position
	Designation	Type[a]	Range					
Heat exchanger vacuum gap	[c]P-501	UPS	0 to 50 psia	ACM	1 psia	5 psia	Alarm (high)	C4
Inpile tube jacket static helium pressure	[c]P-503	UPS	0 to 50 psia	RSBP	35 psia	40 psia 45 psia 0 psia	Alarm (high) Safety (1) Safety (1)	F8 A1 A1
Equipment tank ambient pressure	P-504	UPS	0 to 50 psia	ASCR	19 psia	30 psia	Alarm (high) Alarm (low)	D8 D8
Primary water pressure	[c]P-201	UPS	0 to 200 psia	ACM	100 psia	80 psia 150 psia	Alarm (low) Alarm (high)	D7 D6
Primary water temperature	T-221	C-A	50° to 250° F	ACM	150° F	160° F	Alarm (high)	D5
First-stage compressor cooling water outlet temperature	[c]T-321	C-A	50° to 200° F	ACM	100° F	110° F	Alarm (high)	A6
Second-stage compressor cooling water outlet temperature	T-322	C-A	50° to 200° F	ACM	100° F	110° F	Alarm (high)	B6
Heat exchanger cooling water outlet temperature	[c]T-323	C-A	50° to 250° F	ACM	Test dependent	Test dependent	Alarm (high)	C3
Tank ambient temperature	T-525	C-A	-------------	Portable potentiometer	-------------	-------------	-------------	------
First- and second-stage compressor cooling water flow	FS-342	Flow switch	-------------	-------------	-------------	3 gal/min	Alarm (low)	B5
Heat exchanger cooling water flow	FS-343	Flow switch	-------------	-------------	-------------	10 gal/min	Alarm (low)	C2
Primary water flow	FS-241	Flow switch	-------------	-------------	-------------	10 gal/min	Alarm (low)	D4
Instrument junction box temperature	T-521	C-A	-------------	Data logger	80° F	-------------	-------------	------
Inpile tube wall temperature	[c]T-522	C-A	0 to 400° F	RSBP	235° F 300° F	275° F 275° F	Alarm (high) Safety (3)	E1 A1
Inpile tube wall temperature	T-523 T-524	C-A C-A	0 to 400° F 0 to 400° F	Data logger Data logger	------------- -------------	------------- -------------	------------- -------------	------ ------
Sump water level	LS-161A LS-161 LS-162	Level switch Level switch Level switch	0 to 3 in. 3 to 6 in. 6 to 9 in.	------------- ------------- -------------	------------- ------------- -------------	3 in. 6 in. 9 in.	Alarm Safety (3) Alarm	E7 F1 E8
First-stage compressor power	-------	Relay	On-off	-------------	-------------	Off	Alarm	A2
First-stage compressor current	I-101	Current transformer and ammeter	-------------	Meter relay	Approx. 24 A	116 percent of normal	Alarm (overload)	A3
Second-stage compressor power	-------	Relay	On-off	-------------	-------------	Off	Alarm	B2
Second-stage compressor current	I-102	Current transformer and ammeter	-------------	Meter relay	Approx. 24 A	116 percent of normal	Alarm (overload)	B3
First-stage MG set current	-------	Overload relays	-------------	-------------	-------------	-------------	Alarm (overload)	C5

[a]C-A, Chromel-Alumel thermocouple; P-PR, platinum - platinum 13 percent rhodium thermocouple; UPS, unbonded strain gage pressure sensor; VTFT, Venturi-type flow tube.

[b]ACM, amplifier and control meter; ASCR, amplifier and strip-chart recorder; RSBP, recording self-balancing potentiometer.

[c]These instrument channels are also read out by data logger.

[d]Type of safety action: safety (1), Automatic reactor slow scram; safety (2), automatic reactor fast reverse; safety (3), automatic reactor slow setback.

TABLE IV. - Concluded. INSTRUMENTATION, ALARM, AND SAFETY ACTION TABLE

Variable	Transducer			Readout instrument[b]	Normal reading	Set point	Action	Annunciator position
	Designation	Type[a]	Range					
Second-stage MG set current	-------	Overload	-------------	------------	--------------	------------	Alarm (overload)	C6
Recorder power	-------	Relays	On-off	------------	--------------	Off	Alarm	C7
Instrument amplifiers function selector position	-------	Water switch contacts	Calibrate, zero, operate	------------	--------------	Off-operate	Alarm	B7
Valve V-403 position	LS-403	Limit switch	Open-closed	------------	--------------	Open	Alarm	B8

[a]C-A, Chromel-Alumel thermocouple; P-PR, platinum - platinum 13 percent rhodium thermocouple; UPS, unbonded strain gage pressure sensor; VTFT, Venturi-type flow tube.

[b]ACM, amplifier and control meter; ASCR, amplifier and strip-chart recorder; RSBP, recording self-balancing potentiometer.

from the control set point, the controller produces a change in its control output, and the servoamplifier converts this signal to a signal suitable for operating the servovalve.

The servovalve controls the flow of oil to the hydraulic valve actuator of throttle valve V-101; thus, the valve position is adjusted in the direction indicated by the magnitude and direction of change in the control signal. Feedback information of valve position is provided to the controller by a signal from a differential transformer. Besides providing the controller with feedback, this signal is also used to provide a meter indication of throttle valve position. The feedback components, consisting of the differential transformer and the coherent-signal servodemodulator, are fixed gain devices, which are energized by a well-regulated oscillator power supply to give a reliable indication of valve position.

The controller stability tests and analysis are presented in appendix D. It was found that the controller reset (integral control) adjustment requirement was 30 resets per minute and that the proportional band (gain) adjustment had enough range to give sufficiently fast but stable control. A switch-operated set-point change of 15° F is provided on the controller to give a convenient means for adjusting the proportional band experimentally so that the response obtained has a slight overshoot but does not oscillate.

The controller can also be operated in a manual mode simply by throwing a selector switch from the automatic to the manual position. The valve is then manually positioned by adjusting a potentiometer. In the event of a loss of either automatic or manual control signal, a spring will drive the valve to its fully open, or fail-safe, position and permit maximum cooling of the test specimen.
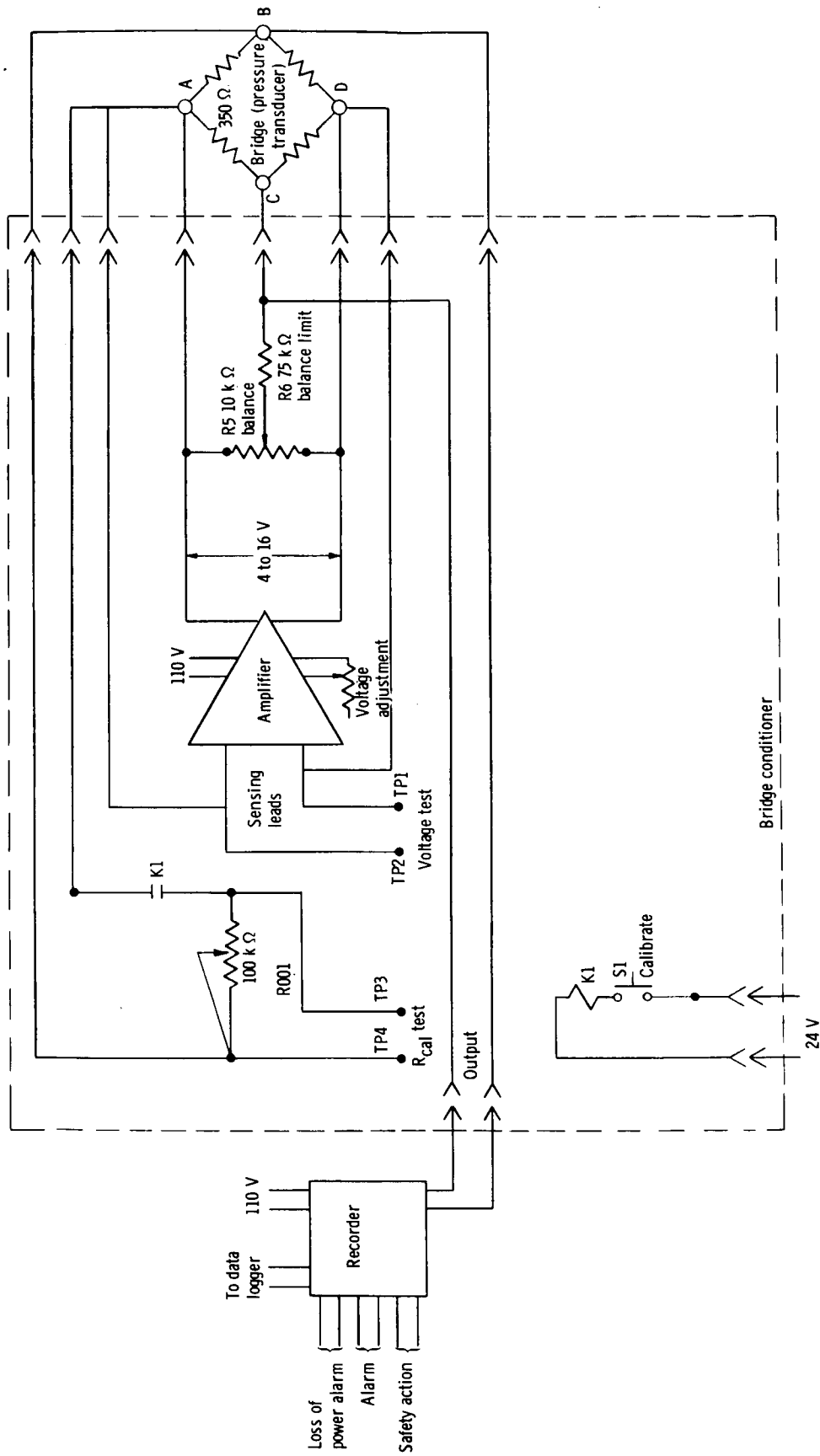
Instrumentation

All the instrumentation of the loop is given in table IV.

Typical pressure channels. - Schematic diagrams for a typical channel are shown in figure 25(a). The front panel layout, presented in figure 26, shows the 14 strain-gage
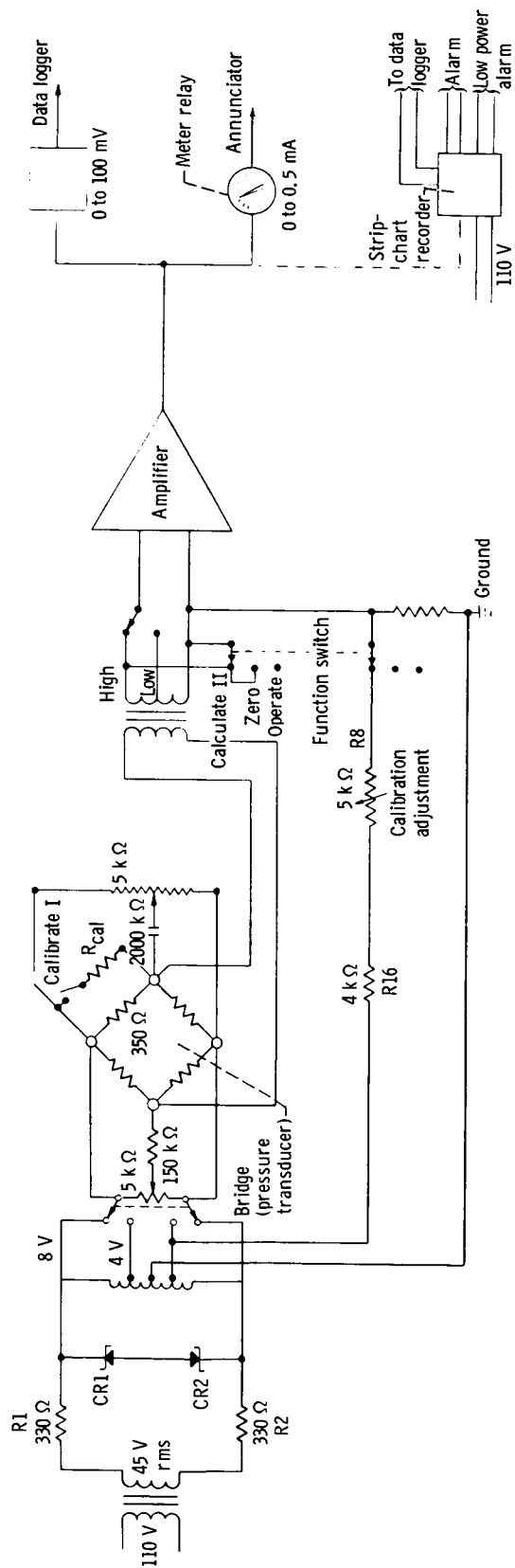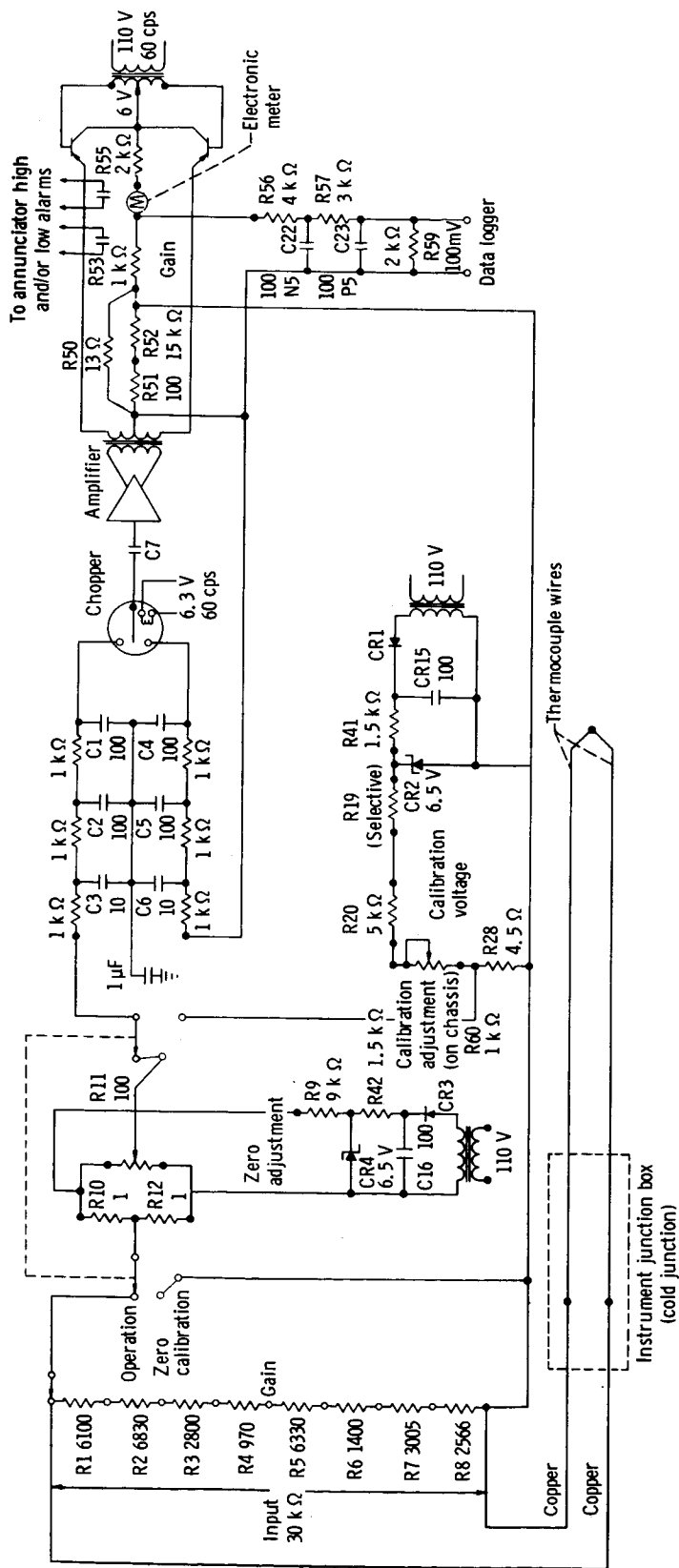
(a) Alarm pressure and flow channel.

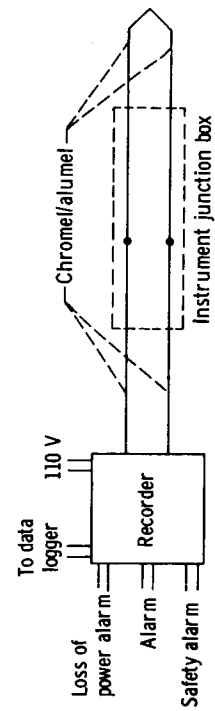Figure 25. - Instrumentation channels.
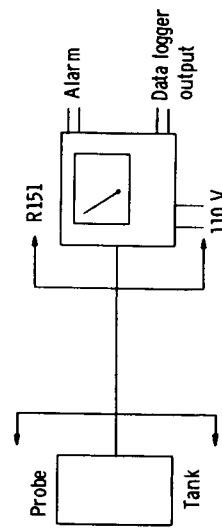
(b) Safety pressure and flow channel.

Figure 25. - Continued.

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(c) Alarm thermocouple channel.

(d) Safety thermocouple channel.

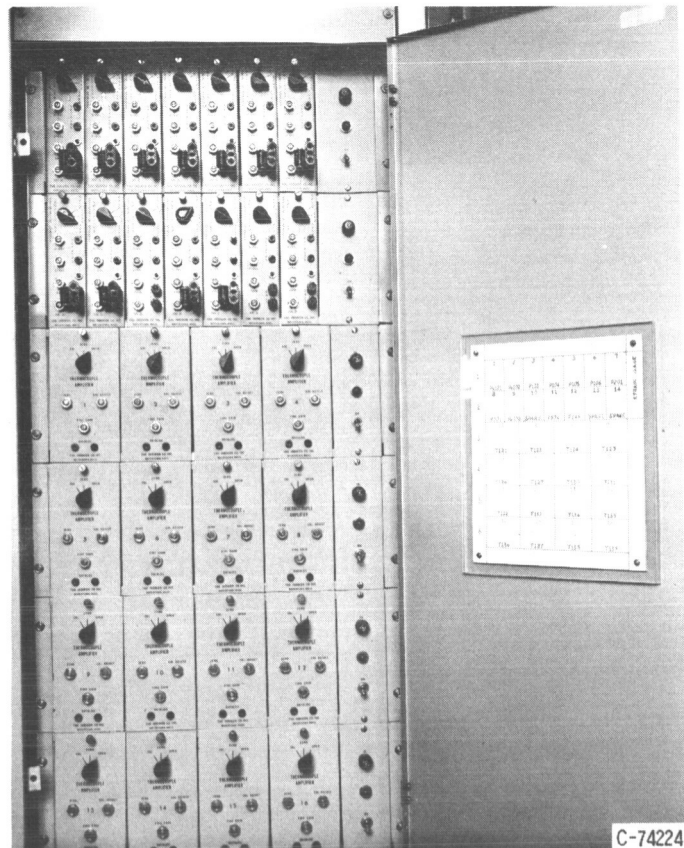(e) Radiation channel.

Figure 25. - Concluded.

Figure 26. – Thermocouple and pressure sensor amplifier panel.

modular amplifiers (5 spares provided). Panel meters provide a visual readout for nine pressure measurements of the loop. The strain-gage amplifiers used in these channels provide the excitation voltage for the pressure transducers and a dual output for the panel meters and the data logger.

The pressure channel calibration is explained in appendix E. Two typical calibrations are presented.

The channel gives a nominal accuracy of 1 percent of full scale for both short-term and long-term (2000 hr) operation. This limit is maintained for line voltage changes from 110 to 130 volts. Gain stability and zero shift each within $\pm 1/2$ percent of full scale for ambient temperature changes of 70° to 110° F. The time response of the amplifier and pressure sensor combination is 1/2 second.

With the use of a six-wire system between transducer and amplifier, two wires are available for the calibrating resistor R_{cal} (fig. 25(a)) so that cable voltage drop errors are eliminated. The plug-in type calibrating resistor R_{cal} can be seen on the front panel of each amplifier in figure 26. It is adjusted during the actual pressure calibration of the channel to give the same output as full-scale pressure. The voltage calibration, calibrate II of the operate switch, is obtained from the regulated excitation voltage and is

adjusted to give 90 percent of full-scale output and is applied as shown in figure 25(a) at the input of the amplifier. The calibrate voltage can be applied during operation to check the operating condition of the channel, but the bridge zero balance adjustment and the use of R_c are limited to the condition of zero pressure to the transducer. The zero position of the function switch gives a shorted amplifier input position that can be used to check for spurious amplifier voltages and to adjust the mechanical zero of the output meters.

The equipment tank ambient pressure (P-504) channel also uses a strain gage amplifier, but the panel meter output drives a strip-chart recorder, which indicates and records the pressure. The recorder has a 1-second full-scale response and an accuracy of 0.5 percent of full scale. A retransmitting slide wire provides the data logger output, and the instrument has cam-operated microswitches for both high and low alarms. The ambient temperature range is 40° to 120° F with a ±0.5 percent of full-scale error limit for a 50° F change.

The channel shown in figure 25(b) is used for two safety channels: the in-pile tube inlet pressure (P-107) and the in-pile tube static jacket pressure (P-503). Each channel consists of a commercially available direct-current bridge conditioner delivering 4 to 16 volts, an unbonded strain-gage pressure sensor, and a strip-chart recorder. The response of the recorder and channel is 1 second full scale, and the channel has an accuracy of ±0.5 percent of full scale. The strain gage system has eight wires to eliminate lead voltage-drop errors and an R_c calibrate resistor. Both recorders have alarm set points and both high- and low-pressure safety set points. The recorders have fail-safe amplifiers and retransmitting slide wires for transmitting data to the data logger. The five bridge conditioners (one spare) are shown in figure 27.

Flow measuring channels. - The helium flow is measured at two places in the system: Total flow just upstream of the bypass line (fig. 8, p. 12) and test specimen flow upstream of the test section. In the total flow circuit (F-146), the transducer is a differential pressure alternating-current strain gage bridge sensor used in conjunction with a venturi flow tube. The circuit schematic is similar to that shown in figure 25.

Test element flow recorders (F-147 and F-147A) are safety channels, and the channel shown in figure 25(b) is also used. In these cases, a strip-chart recorder with a full-scale response of 0.25 second and an accuracy of 0.3 percent of full scale is used. There are safety set points both upscale and downscale of the normal readings.

The calibration tests and analyses for the test element gas flow meters are given in appendix F. This work was necessary to determine accurate test specimen heat output from the helium coolant mass flow measurements as well as the helium temperature rise. The tests demonstrated that an accuracy of ±0.5 percent of the instrument reading existed in the flow measurements.
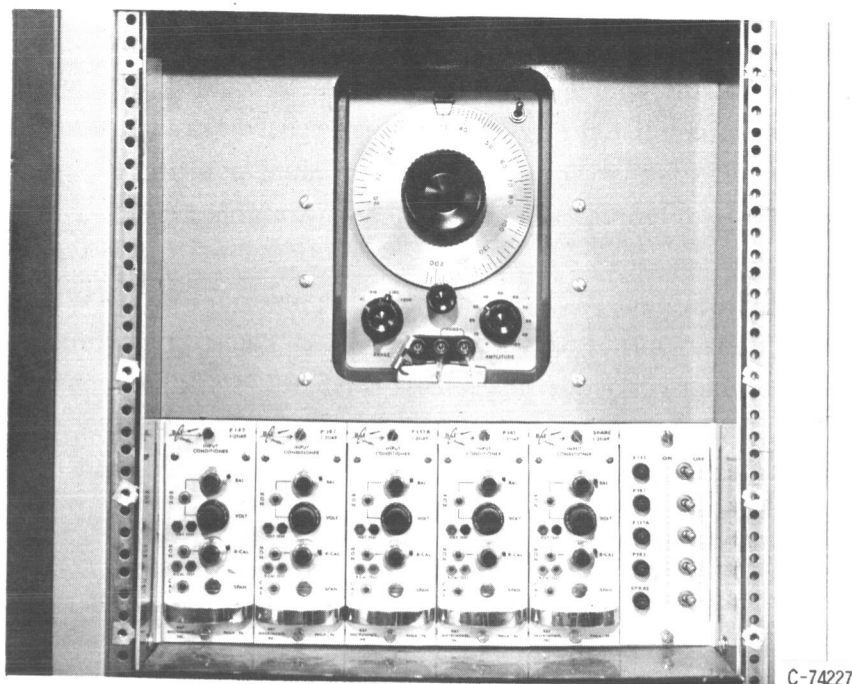
C-74227

Figure 27. - Bridge conditioners.
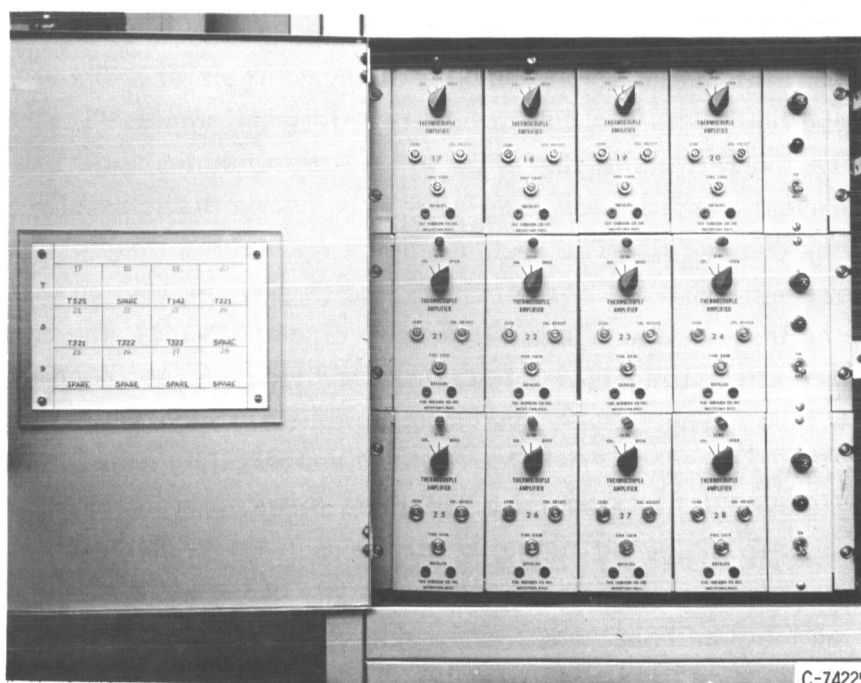
C-74225

Figure 28. - Thermocouple amplifier panel.

There are also three channels that indicate a loss of water flow on the annunciator: first- and second-stage compressor cooling water flows FS-342; heat exchanger cooling water flow FS-343; and primary water flow FS-241. The wiring for these circuits is shown in figure 23.

Temperature channels. - Panel meters provide a visual readout of temperature for 22 of the 30 thermocouples in the loop. A schematic diagram of a typical channel is shown in figure 25(c). A chopped thermocouple voltage is supplied to an alternating-current amplifier. A coherent-signal detector supplies a feedback voltage to stabilize the amplifier. The entire input-feedback circuit is floating so that grounded thermocouples can be accommodated. The amplifiers are modularly constructed packages (six spares provided, see figs. 26 and 28). The modular construction and spare amplifiers minimize the repair time for any particular channel and provide easy access for service. All the thermocouples, which terminate in panel meters, have cold junctions at the instrument junction boxes.

With regard to stability, the channel has a nominal accuracy limit of ±1 percent of full scale for both short- and long-term (2000 hr) operation. Half of this limit is needed for line voltage changes with limits of 110 and 130 volts and the other half for ambient temperature changes with limits of 70° and 110° F. The output is linear to within ±1 percent of full scale. The calibrating voltage is stable to within ±1 percent of full scale when the preceding voltage and temperature limits are used. The time constant of the input circuit with the input thermocouple attached is less than 1 second, and this is approximately the response of the channel. The calibration voltage, after it is adjusted by means of the front panel screwdriver adjustment, is used during loop operation to adjust the data logger output to 90 percent of full scale by means of the fine gain control.

One of the three test specimen exit gas temperature thermocouples (T-129) feeds directly to a strip-chart recorder. This recorder is part of the exit gas temperature loop control system and is shown in figure 22(b).

The remaining two test specimen exit gas temperature thermocouples (T-128 and T-128A) also feed directly to strip-chart recorders. These are safety channels that have alarm and safety set points and provide signals to the data logger. The schematic diagram for channels T-128 and T-128A is shown in figure 25(d). All three recorders (T-128, T-128A, and T-129) have fail-safe amplifiers and upscale drive in case of thermocouple burnout.

The purpose of the three thermocouples mounted in the inpile tube is described in the section entitled Inpile Tube Assembly. Their channels consist of the following. One of the core-side thermocouples, T-522, is wired to a recorder to form a safety channel similar to that shown in figure 25(d). This recorder is equipped with (1) alarm and safety set points, (2) a retransmitting slide wire to be used by the data logger,

(3) an upscale drive in case of thermocouple burnout, and (4) an upscale-drive fail-safe amplifier.

The remaining core-side thermocouple, TE-523, and the opposite-side thermocouple, TE-524, are fed directly to the data logger. The instrument junction box temperature (cold junction, T-521) and the inlet-gas-temperature thermocouple (T-140) are wired directly the the data logger, also.

Radiation instrument channel. - The gamma radiation detector, R-151, at the helium system filter is the only radiation monitoring channel (fig. 25(e)). The probe of the commercially available radiation detector is a compact unit consisting of an air-equivalent ionization chamber coupled to an electrometer-type vacuum tube, which is connected as a cathode follower. The output of the cathode follower is measured by a commonly used vacuum-tube voltmeter circuit, which is located in the meter chassis at the console and electrically connected with the probe through the cabling. The range of the channel is from 20 to 1000 roentgens per minute, which is consistent with a background at the filter of approximately 200 roentgens per hour.

Available Instrumentation and Control in Transport

The following are operable during loop transport from the reactor to the hot cell:

P-503	in-pile tube static helium pressure
V-101	main helium control valve (operable only if all loop scram channels are clear)
V-102	valve position of bypass helium control valve
T-123	heat exchanger inlet gas temperature
T-129	test specimen exit gas temperature
T-131, 134, 137	test specimen plate temperature
P-107	inlet to inpile tube helium pressure
F-147	test-specimen helium flow
FS-342	first- and second-stage compressor coolant water flow
FS-343	heat exchanger coolant water flow
LS-161, 161A	sump pump operator
LS-162	sump water level
T-521	instrument junction box temperature
T-522	inpile tube wall temperature

Alarm and Safety Features and Design Criteria

The alarms and automatic safety actions associated with the operating parameters and equipment of the loop are tabulated in table IV. If a backup for any safety action is not normally supplied by another channel, then the principle of duality is applied. Examples of this are the two helium flow channels and the two channels for helium temperature measurement downstream of the specimen.

Precautions were taken to make it extremely improbable that excessive temperature or insufficient pressure or flow could exist without the readout instrument going off scale if any change occurred in amplifier gain or other malfunction within a safety or alarm channel that would be sufficient to change the original calibration.

Safety channel recorders. - All recorders are self-balancing potentiometers, which are feedback instruments having their gain fixed or determined by passive elements. The recorders have upscale drive if the thermocouple circuit or other transducer burns out or opens the recorder input for any reason. They also have upscale drive if the recorder amplifier loses its gain through an open or short in any of its three amplifier stages. The upscale travel results in a safety action through the high-limit switch, which exists on all safety channels.

In addition, the principle has been followed that any malfunction in a safety channel should give the same safety action as its limit; therefore, an excessively low temperature and excessively high flow or pressure also give safety actions so that a normal reading is bracketed at the top and bottom by a safety action. As an additional backup, alarms precede all safety actions on each recorder as indicated in table IV.(pp. 52 to 54).

The alarm and safety contacts are microswitches, which are operated by a cam that is mechanically connected to the indicating pointer of the recorder. Loss of power to the two-phase servomotor and amplifier of the recorder causes an alarm.

Alarm channel amplifiers. - Both the strain gage and the thermocouple amplifier are feedback devices, and their gain is established by passive elements. Both types of amplifiers have zero and calibrate switch positions in addition to operate, and an alarm occurs if the switch is not in the operate position.

The remaining control of the strain-gage amplifier is a pushbutton (spring return) for applying a calibrating resistor across one leg of the pressure sensor bridge.

A power failure or gain loss in either type of amplifier will give a low off-scale reading and an alarm if a low limit on readout exists. The pressure transducer operates from the alternating-current power and is protected from loss of power by this same action.

Transducer malfunction. - The pressure transducers have overrange capabilities of 200 to 1000 percent of their normal range without changes in calibration. Opening of any leg of the strain-gage bridge of the pressure sensor or loss of power to the bridge in

either the alarm or safety channels will give either a high or low off-scale reading. In the case of the thermocouple amplifier, opening the thermocouple will give a low off-scale reading. These conditions are easily recognizable and in case of the existence of low or high limits will also given alarms.

Safety Channels

The eight instrumentation channels that initiate safety action by reducing reactor power are shown in table V, and the safety control relays operated by these channels are shown in figure 29.

A safety action may be more or less severe, both as to extent and speed with which it affects the reactor and as to how much trouble it is to recover from it and resume operation. The fastest and most complete of the safety actions is the slow scram, which provides a shutdown by dropping all rods. The time between the reception of the scram signal by the the reactor circuitry and initial falling of the rods is approximately 80 milliseconds. A fast reverse causes a fast power reduction and eventual shutdown by driving all the shim-safety rods down at a rate of 9 inches per minute. The final and least drastic of the safety actions is the slow setback. The slow setback produces a reduction in power in a 110- to 55-second period to its lower limit of 0.03 percent of full power.

The procedure and results on the dead-time measurement of seven safety channels are explained in appendix G.

TABLE V. - SAFETY CHANNEL INSTRUMENTATION

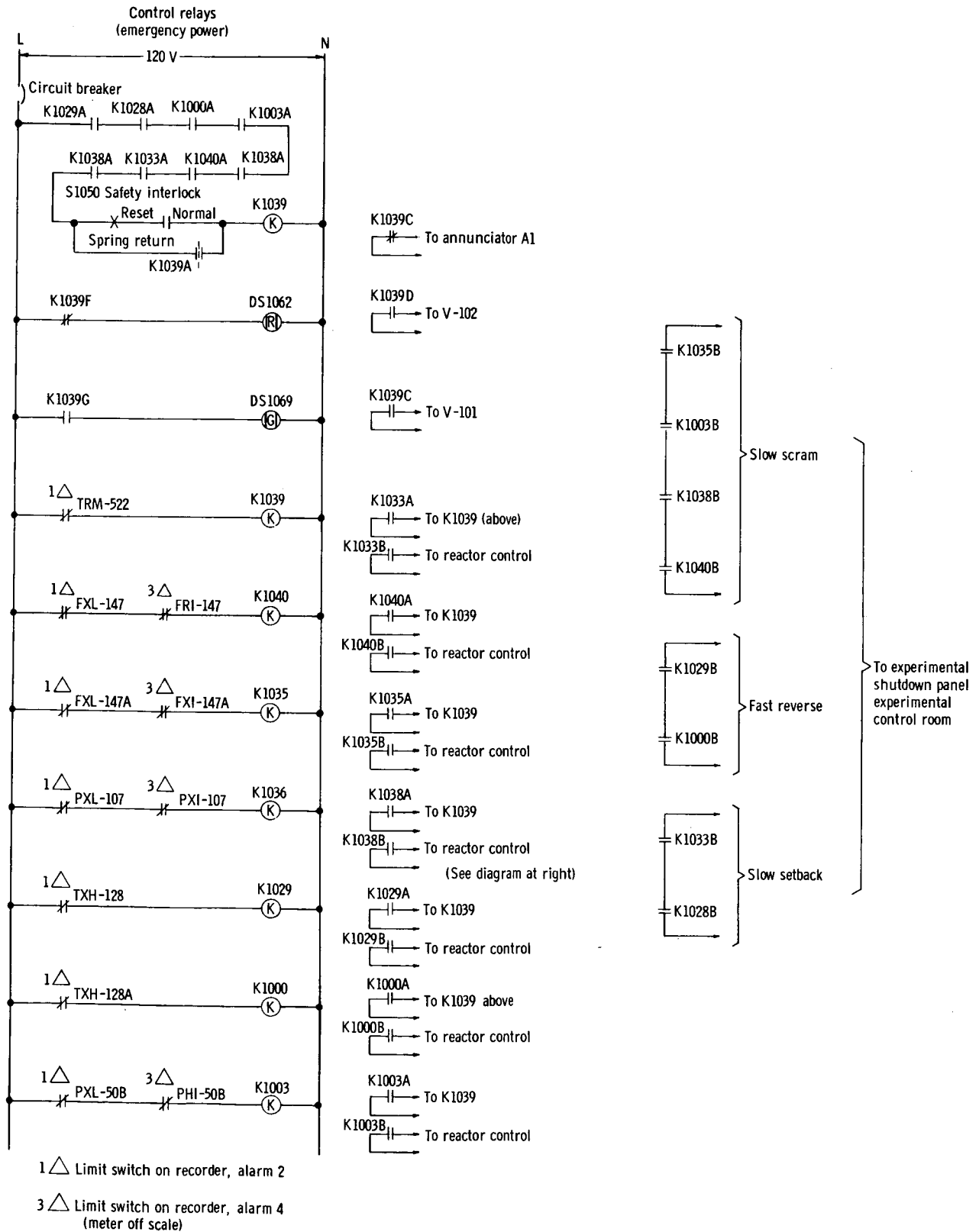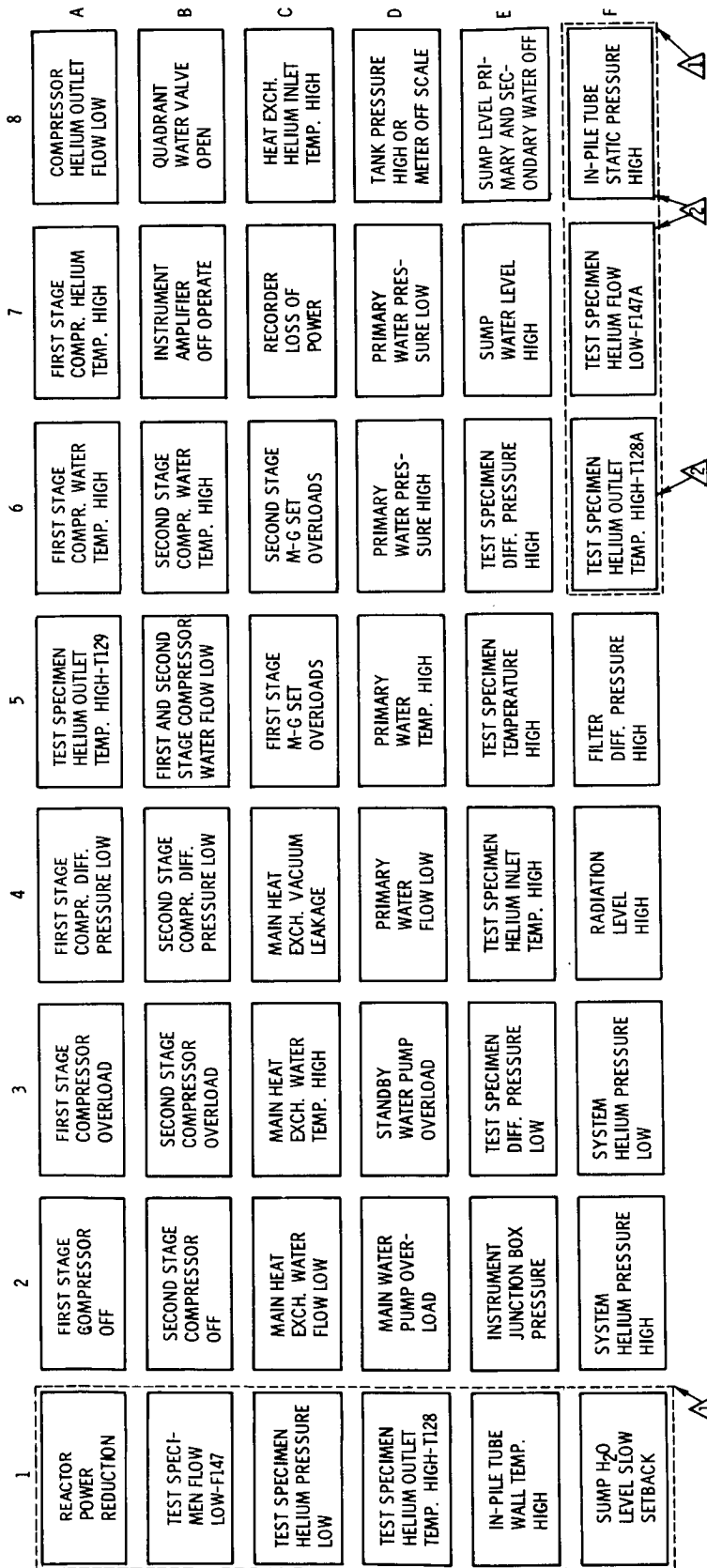| Channel	Sensor	Mode of reactor power reduction
Test specimen outlet helium temperature	T-128	Fast reverse
Test specimen outlet helium temperature	T-128A	Fast reverse
In-pile tube inlet helium pressure	P-107	Slow scram
Test specimen helium flow	F-147	Slow scram
Test specimen helium flow	F-147A	Slow scram
Inpile tube wall temperature	T-522	Slow setback
Inpile tube static jacket static helium pressure	P-503	Slow scram
Sump level switch	LS-161	Slow scram

Figure 29. – Safety control relays.

	1	2	3	4	5	6	7	8
A	REACTOR POWER REDUCTION	FIRST STAGE COMPRESSOR OFF	FIRST STAGE COMPRESSOR OVERLOAD	FIRST STAGE COMPR. DIFF. PRESSURE LOW	TEST SPECIMEN HELIUM OUTLET TEMP. HIGH-T129	FIRST STAGE COMPR. WATER TEMP. HIGH	FIRST STAGE COMPR. HELIUM TEMP. HIGH	COMPRESSOR HELIUM OUTLET FLOW LOW
B	TEST SPECIMEN FLOW LOW-F147	SECOND STAGE COMPRESSOR OFF	SECOND STAGE COMPRESSOR OVERLOAD	SECOND STAGE COMPR. DIFF. PRESSURE LOW	FIRST AND SECOND STAGE COMPRESSOR WATER FLOW LOW	SECOND STAGE COMPR. WATER TEMP. HIGH	INSTRUMENT AMPLIFIER OFF OPERATE	QUADRANT WATER VALVE OPEN
C	TEST SPECIMEN HELIUM PRESSURE LOW	MAIN HEAT EXCH. WATER FLOW LOW	MAIN HEAT EXCH. WATER TEMP. HIGH	MAIN HEAT EXCH. VACUUM LEAKAGE	FIRST STAGE M-G SET OVERLOADS	SECOND STAGE M-G SET OVERLOADS	RECORDER LOSS OF POWER	HEAT EXCH. HELIUM INLET TEMP. HIGH
D	TEST SPECIMEN HELIUM OUTLET TEMP. HIGH-T128	MAIN WATER PUMP OVERLOAD	STANDBY WATER PUMP OVERLOAD	PRIMARY WATER FLOW LOW	PRIMARY WATER TEMP. HIGH	PRIMARY WATER PRESSURE HIGH	PRIMARY WATER PRESSURE LOW	TANK PRESSURE HIGH OR METER OFF SCALE
E	IN-PILE TUBE WALL TEMP. HIGH	INSTRUMENT JUNCTION BOX PRESSURE	TEST SPECIMEN DIFF. PRESSURE LOW	TEST SPECIMEN HELIUM INLET TEMP. HIGH	TEST SPECIMEN TEMPERATURE HIGH	TEST SPECIMEN DIFF. PRESSURE HIGH	SUMP WATER LEVEL HIGH	SUMP LEVEL PRIMARY AND SECONDARY WATER OFF
F	SUMP H2O LEVEL SLOW SETBACK	SYSTEM HELIUM PRESSURE HIGH	SYSTEM HELIUM PRESSURE LOW	RADIATION LEVEL HIGH	FILTER DIFF. PRESSURE HIGH	TEST SPECIMEN HELIUM OUTLET TEMP. HIGH-T128A	TEST SPECIMEN HELIUM FLOW LOW-F147A	IN-PILE TUBE STATIC PRESSURE HIGH

△1 ALARMS ON OPEN - ALL OTHERS ALARM ON CLOSE

△2 PAINT AREA INDICATED WITH RED PAINT

Figure 30. - Annunciator panel.

Annunciator

The annunciator gives both audible and visual alarm indications. It has 48 signal positions, eight columns wide by six rows high. Figure 30 shows the annunciator layout and the abnormal conditions that cause alarms. Each signal has two lights, one red and one white. Each light has two lamps in parallel so that the burnout of one lamp will not take a point out of operation. Forty-five points are normally open and alarm on contact closure. The operational sequence is given in table VI.

TABLE VI. - OPERATIONAL SEQUENCE

	Normal	Off normal	Off normal acknowledged[a]	Off normal to normal, not acknowledged[b, c]
Red light	Off	On	Off	On
White light	Dim	Flashing	On	Dim
Horn	Off	On	Off	Off

[a]A return to normal condition while in "off normal acknowledged" position will automatically reset to "normal".

[b]A return to off normal condition while in "off normal to normal, not acknowledged" position will automatically reset to "off normal".

[c]Pressing the acknowledge button when in the "off normal to normal, not acknowledged" position will automatically reset to "normal".

A test button is available to give contact closure to all normally open points and contact opening to all normally closed points. This is done by paralleling alarm contacts with relay contacts for normally open points and having relay contacts in series with alarm contacts for normally closed points.

Experimental Procedure

The general procedure used in preparing, conducting, and completing an irradiation test is given in the Test Procedure section. Further details on this procedure are presented in the following paragraphs.

Preirradiation Hot Lab Procedure

The procedure starts in the hot lab with the loop in the position shown in figure 3(a)

(p. 6). The end of the inpile tube with the removable end caps is in the hot cell. A typical test section, such as that shown in figure 13 (p. 23) is inserted into the inpile tube with the remote handling tools available in the hot cell. The test section assembly includes the inner pressure vessel end cap and the mating half of the thermocouple plug (17 thermocouples for test section temperature measurements).

At the mating interface of the end cap and the tube, two 1/4-inch O-rings form the seal for two test section differential pressure measurement lines. A $5\frac{3}{4}$-inch O-ring forms the inner pressure vessel seal. The test section is bench assembled with radioactively clean parts. Figure 12 (p. 20) shows the test section installed in the tube with the end caps and thermocouple plug assembled.

Special tools and guide fixtures are used to aline and guide the test section assembly to its proper position in the tube. After the assembly is positioned, the threaded inner jack ring with its screws is installed. First the ring is tightened, then the screws are tightened to form the inner pressure vessel seal and the differential pressure measuring tube seals. The seal joint is then leak checked with a helium leak detector. The maximum allowable leak rate is limited to 10^{-7} standard cubic centimeters per second for each joint.

While the foregoing procedure is being performed, the thermocouple plug is in the hanging position indicated in figure 12. The thermocouple leads connecting the plug are flexible.

After the leak check is made, the thermocouple plug is connected to its mate on the test section. Special manipulating tools were designed to accomplish this connection. The outer end cap and its O-ring seal is then positioned in the tube. The jack ring and its screws are locked into position, and the screws are tightened to form the outer end cap seal. The joint is leak checked.

While the loop is in the hot lab, four instrument and power cables are connected to the control console through the transport junction box. This connection enables the operators to perform a partial checkout of the instrumentation and operation of the loop at that time.

The helium system and the equipment tank are evacuated with the auxiliary equipment available in the hot cell. Interconnections for the evacuation process exist on the back side of the tank (opposite the inpile tube). Hot lab personnel can make these connections manually since radioactivity is not a problem when the inpile tube is inserted in the hot cell as shown in figure 3(a). Pump down and charging of the helium system is repeated three times to ensure that the system is clean and to reduce the hysteresis of the absolute pressure transducers.

Transporting Loop to Reactor

Prior to transporting the loop to the reactor, the cables are disconnected and

wrapped around the top of the tank.

The inpile tube is withdrawn from the hot cell opening and lowered onto an electrically driven transport dolly located in the hot lab canal. This operation is performed with the hot lab crane (see fig. 3(b)). The loop is then transported to the reactor (quadrant A). A tracking arrangement on the canal and quadrant floors guides the transport dolly during transport (fig. 2, p. 4).

Preirradiation Procedure in Quadrant A

The loop is lifted off the transport dolly and lowered onto the HT-1 guidance tracks by using the reactor crane (see fig. 3(e), guide tracks not shown).

The eight electrical operating cables attached to the equipment tank are connected to the operate junction box located at the edge of quadrant A (see fig. 2). The loop is then connected to a vacuum pump-down system, and the helium system and equipment tank are again evacuated. This is done for the calibration of the absolute pressure channels, which read out through cables not connected in the hot lab. Both zero and span adjustments are then performed on all absolute pressure channels. The thermocouple channels are given both zero and span adjustments while the loop is being evacuated.

The helium system and equipment tank are then charged with helium (to 140 psia) and nitrogen (to atmosphere pressure), respectively. The flexible hoses from the primary cooling water supply and return lines, the secondary cooling water supply and return lines, and the hot drain line from the quadrant service lines are connected by using long-handled tools, to the appropriate piping on the equipment tank by quick-disconnect couplings. The primary and secondary water flow rates to the loop are then set to their desired values. The three sump level switches are then checked for proper operation.

The helium compressors are started and stopped three times to remove the hysteresis from the differential pressure (flow) transducers. A zero and a span adjustment are then performed on the differential pressure instrument channels. The compressors are restarted, and the helium flow is adjusted to the desired values.

Before the inpile tube can be inserted into the HT-1 hole, the primary water supply to the hole is turned off, and the hole purged of primary water. The hole is then opened, and the inpile tube is manually driven into the hole by using the insertion and removal system shown in figure 31. When the inpile tube is fully inserted, the locking lugs mesh with the locking mechanism for HT-1 (see fig. 12). The inpile tube is then locked in place. The hole is purged of quadrant water, and the primary water flow to the hole is set to the desired value.
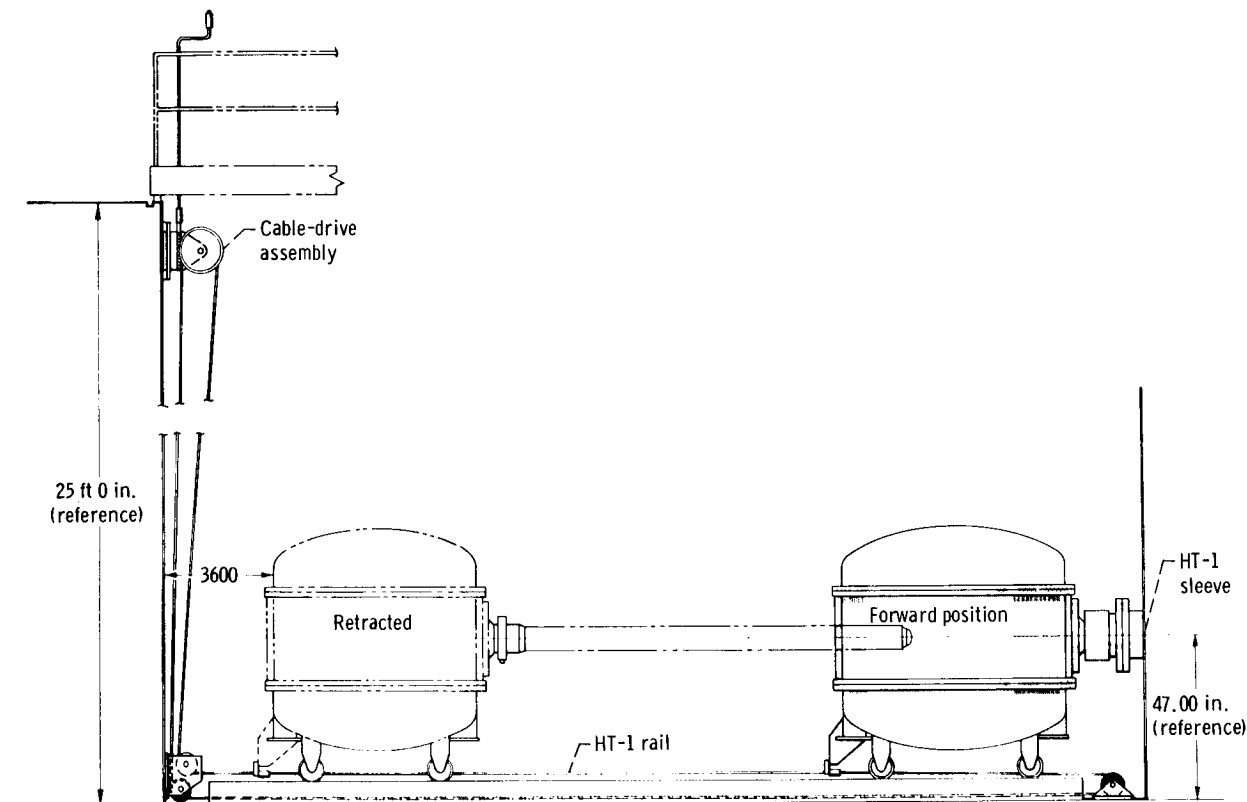
Figure 31. – Insertion and removal of 100-kilowatt helium cooled loop.

A final preoperational checkout is then performed. This consists of checking all eight scram channels and the lights, switches, and meters on the control console to ensure that they are all operating properly. The data logger is started and checked for proper operation. When all systems are operating properly, the reactor can be started.

Irradiation

The reactor is started and brought to zero power by normal reactor operating procedure. The controller for the main helium throttling valve (V-101) is in the manual position. The main helium throttling valve (V-101) and the element bypass throttling valve (V-102) are set to the approximate final steady-state positions as required.

The reactor is brought to the desired power level, and the controller manually operated to bring the test specimen exit gas to the desired temperature or to give a particular flow rate. Helium is added to the main helium system from the high-pressure supply tank to bring the system to the desired operating pressure (~200 psia). The helium throttling valves, V-101 and V-102, are readjusted to obtain the desired temper-

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ature or flow conditions. The controller for V-101 is then switched to automatic operation.

At the end of the test the controller is switched to manual operation, and the reactor is shut down. Since a high exit gas temperature is not required or desirable after the test, valve V-101 is opened to a position that will give adequate helium flow to remove the nuclear afterheat from the test elements at a reduced temperature.

Postirradiation Procedure in Quadrant A

After the reactor has been shut down, the inpile tube must remain in HT-1 for at least 1 hour because of the nuclear afterheat in the reactor core and test specimen. Before the inpile tube is withdrawn, the primary water supply to HT-1 is shut off, and the hole purged. The inpile tube is then unlocked and completely withdrawn.

The flexible primary cooling water supply and return lines are disconnected from the equipment tank. The lines are purged prior to removal. Then the standby water pump is started so that the loop can be cooled with quadrant water. The flexible secondary water supply and return lines and the hot drain line are then disconnected from the equipment tank, and the loop is lifted off the HT-1 guidance tracks and placed on the transport dolly.

Transporting Loop to Hot Cell

Four of the eight electrical cables connected to the operate junction box are disconnected and connected to the transport junction box located in the hot lab by means of long extension cables. During this procedure, one or both compressors and a quadrant water pump along with the necessary instrumentation are kept operating. When this procedure is completed, the remaining four cables are disconnected from the operate junction box and coiled on top of the equipment tank.

The loop is then transported underwater to the hot lab canal. The loop is stored in the canal, if necessary, to allow the fission product afterheat to decay to a sufficiently low value before turning off the compressors and water pump.

Postirradiation Hot Lab Procedures

While the loop is still in the canal, the main helium system is evacuated and purged to the reactor facility off-gas system through the 30-foot-long flexible hose permanently

connected to the loop evacuation and filling line (at valve V-112, fig. 8, p. 12). By lifting the end of this hose out of the canal water and connecting it to the off-gas system above the canal, no water is introduced into the off-gas helium systems. The static gas jacket in the inpile tube will also be evacuated and purged (if necessary) through this same hose by an interconnecting line with valve V-511 (fig. 8) outside the equipment tank.

In the event of a leak in the helium system (expelling gas into the tank atmosphere), the equipment tank can be evacuated and purged to the off-gas system through another 30-foot hose connected permanently to V-502.

The purpose of purging the main helium system and equipment tank gas under water is to prevent the discharge of radioactive gases in the hot lab in the event of a crane accident while moving the loop in the hot lab.

After purging is completed, the loop is lifted out of the canal and placed on the tracks, which aline the inpile tube with the cutoff hole in the hot cell wall. The loop is then pushed forward until the inpile tube section is fully inserted in the cutoff hole by using the hot lab crane (see fig. 3(a), p. 6) for similar procedure).

The outer and inner pressure vessel end caps are removed, and then the test section assembly is removed from the inpile tube. This procedure is similar to that used in the preirradiation hot lab. The test specimen is then disassembled, and any desired inspections and tests are performed. Equipment is available in the hot cell so that the postirradiation studies can be carried out remotely.

Maintenance Capabilities

If a piece of equipment must be repaired or replaced and the tank is at a low level of radioactivity, the necessary work can be done in the hot handling area, behind the hot cell. If the tank is at a high level of radioactivity, the entire loop can be placed in the hot cell through the removable roof slabs, and the required work can be done remotely. A turnover mechanism in the hot cell can rotate the entire equipment tank so that all the equipment is accessible. The turnover mechanism, including the loop, is shown in figure 32.

SYSTEM HAZARDS EVALUATION

Off-normal operating conditions of the loop have been discussed in detail throughout the previous sections. This information has been combined in this section. The most serious failures, which may occur during a test, are presented, and the resulting condi-
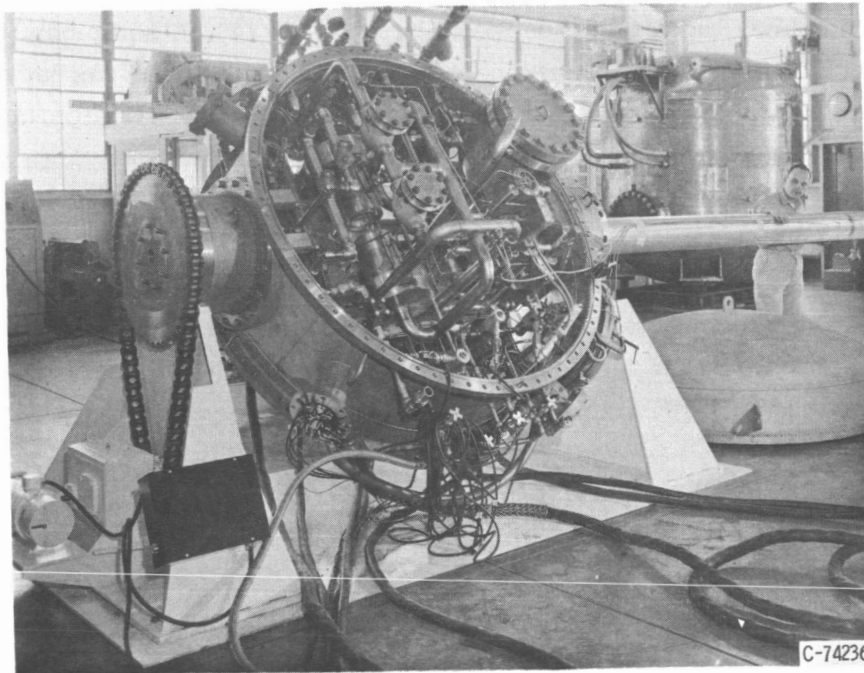
Figure 32. - Turnover mechanism.

tions and safety actions associated with these failures are discussed.

One Compressor Failure

A compressor failure is signalled by the audible and visual alarms associated with the compressor differential pressure indicators Pd-101 and Pd-102. No automatic power reduction is initiated by instrumentation for a compressor not operating; however, the resulting decrease in helium flow may trip other alarms or safety actions.

When one compressor is not operating, the system helium flow is reduced. This raises the test specimen exit helium temperature, which in turn causes valve V-101 to open and the test section helium flow to increase. If a reactor power reduction is initiated, valve V-101 goes to full open, and valve V-102 goes to full close. These valve positions will provide maximum coolant flow to the test section. A reactor power reduction will be initiated by low helium flow and/or high test specimen exit gas temperatures. These instrument channels are F-147, F-147A, T-128, and T-128A (see section entitled Safety Channels).

Loss of Helium System Pressure

The main helium system can lose pressure by leaking gas into either the heat ex-

changer vacuum space, the inpile tube static gas jacket, or the equipment tank. A leak into the heat exchanger vacuum space or into the inpile tube static gas jacket reduces the system pressure slightly, less than 15 pounds per square inch. No appreciable effect on operating conditions is expected. However, alarms and/or safety actions will originate primarily from P-501 (heat exchanger vacuum gap) or P-503 (inpile tube static helium pressure).

A coolant gas leak into the equipment tank would result in a system pressure drop until an equilibrium pressure of approximately 30 pounds per square inch absolute is reached in the helium system and equipment tank. An alarm and reactor power reduction will be initiated by P-107 (inpile tube inlet pressure recorder).

Loss of Electrical Power

Electrical power is supplied to the loop components from a commercial electric power bus and an emergency power bus to which four diesel generating units are connected. This arrangement was described in the section entitled Electrical Systems. During normal operation the diesel units run at reduced load, and the emergency power bus is partially supplied with commercial power.

In the event of a commercial power failure, the diesel units will supply power to the emergency bus, but no power will be supplied to the commercial bus.

Loss of diesel power - commercial power unaffected. - Since the commercial circuits are capable of providing power to the entire Plum Brook Reactor Facility, loss of the diesel power source will cause no change in the operation of the loop; however, the loop (and the reactor) will be shut down because of safety requirements of the Plum Brook Reactor Facility.

Loss of commercial power - diesel power operating properly. - The most significant effect of this type of failure is the loss of the first-stage compressor C-101 (see One Compressor Failure section).

Simultaneous loss of commercial and emergency power. - This type of failure results in a complete loss of helium flow and electrical power to the loop. The reactor will scram, and the reactor and all inpile experiments will be cooled by gravity flow from a large water storage tank. The secondary cooling water inlet and exit valves (V-301 and V-308) fail open and allow flow to the heat exchanger and compressors. The primary water inlet valve (V-204) fails closed, but a bypass line around it permits flow to to the shield water pressure vessel.

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Instrument Failure

All instrument channels that can initiate a reactor power reduction will also cause a reactor power reduction in the event of a sensor failure. Deatiled information on the fail-safe features of these channels is given in the section entitled CONTROL AND INSTRUMENTATION.

Control System Failure

The recorder-controller monitors and controls the test specimen exit gas temperature through a thermocouple (T-129) located in the exit gas stream (see fig. 8, p. 12). The recorder-controller will drive upscale and cause a reactor power reduction in the event the sensing thermocouple burns out.

If power is lost to the electrohydraulic actuating system of either valve V-101 or V-102, the valve in question goes to its fail-safe position and provides increased coolant flow to the test specimen. An automatic reactor power reduction will not be directly initiated by this type of failure, but other alarms or safety actions may be initiated.

Heat Exchanger Bayonet Tube Leak

Leakage of gas or water into the evacuated space between the two barriers is indicated by P-501 (head-exchanger vacuum gap). The alarm set point is 5 pounds per square inch absolute. The heat exchanger is capable of operation if either of the two barriers separating the helium and water is ruptured; however, because of safety requirements, the reactor will be shut down, and the experiment terminated.

Loss of Inpile Tube Shield Water

The instrumentation provides alarms to indicate a loss or reduction of shield water flow. Instrument channel P-201 (primary water pressure) provides a continuous indication of primary water pressure and will give an alarm when the pressure exceeds 150 pounds per square inch absolute or falls below 80 pounds per square inch absolute. Instrument channel T-221 (primary water temperature) provides a continuous indication of temperature and will give an alarm when the temperature exceeds 160° F. Instrument channel FS-241 (primary water flow) will signal a complete loss of water flow. A partial loss of water flow will be indicated by a greater than normal temperature indication on T-221.

Loss of HT-1 Coolant Water Flow

For a step loss of HT-1 coolant water flow, it was determined that a set point of 300° F for T-522 (inpile tube wall temperature) with a reactor power reduction by means of a slow setback provides adequate protection for the aluminum portion of the inpile tube.

For purposes of analysis, the accident was assumed to be a step loss of water flow with no heat transfer at the outside diameter of the aluminum portion of the inpile tube. The characteristics of the instrumentation and reactor were also taken into consideration. The temperatures and stresses were determined by the methods given in appendix A. The analysis shows that the temperatures and stresses are well within allowable limits.

Loss of Secondary Cooling Water

Secondary water is used to supply cooling water to the equipment within the tank. Failure of this supply initiates the operation of the quadrant water pump for an emergency supply. Pump operation is initiated by instrument channels FS-342 (first- and second-stage compressor cooling water flow) and FS-343 (heat-exchanger cooling water flow).

Water and Helium Leaks

The reactor hot-drain and off-gas systems are capable of handling leakage of helium from the gas system and water leakage from the fluid systems into the equipment tank (see Hot-Drain and Off-Gas Systems section). All important components and wiring within the tank are capable of withstanding a high-pressure spray-type water leak. Waterproof insulation of the hot gas pipes protects them from undue stresses resulting from a leak. Steam formation can be handled by the hot-drain and off-gas systems.

Loss of Helium Flow

The maximum accident for this facility is loss of helium flow. When helium flow is lost, a slow scram will be initiated by F-147 or 147A. The transient temperatures in the steel and aluminum pressure vessels were calculated based on the following assumptions:

(1) The loss of helium flow is a step change.

(2) Full reactor power for 0.380 second follows initiation of scram signal from F-147 or 147A (t = 0 to 0.380 sec).

(3) When t = 0.380 second, reactor gamma power drops to 40 percent of full value and remains at this level for 1 second (t = 0.380 to 1.380 sec).

(4) After t = 1.380 seconds, the gamma power decays exponentially.

The maximum temperature of the steel pressure vessel is reached at t = 0.380 second. The temperature of the aluminum pressure vessel does not increase because the heat generated in it is transferred to the water flowing in HT-1.

Thus, it can be concluded that the structural integrity of the inpile tube is not endangered in any way by a serious accident.

Note that the analysis does not consider the test specimen. The test conditions are chosen so that the test specimen remains below its melting point during any credible accident or malfunction. Thus, the test specimen places no additional burden on the structural integrity of the inpile tube during the maximum accident. The loop operating limitations are discussed in the section Operating Characteristics, Limitations, and Requirements.

Lewis Research Center,
        National Aeronautics and Space Administration,
                Cleveland, Ohio, October 31, 1966,
                        120-27-04-57-22.

APPENDIX A
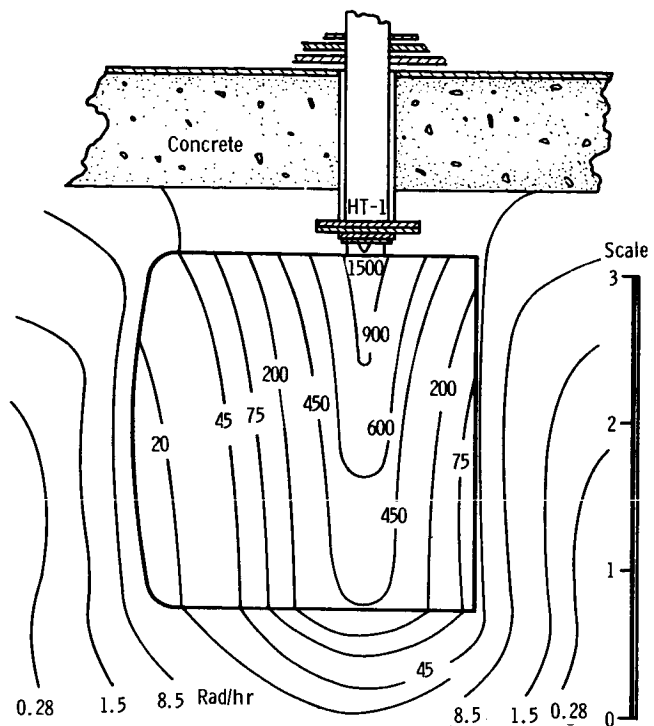
NUCLEAR CALCULATIONS

Shielding Calculations

Shielding calculations were performed to obtain an isodose plot in and around the equipment tank. These plots are shown in figures 33(a) and (b). With the dose rate and the exposure time, it was possible to determine the damaging effects of radiation on the equipment and instrument materials.

The calculation consisted of finding (1) attenuation factors, (2) the neutron flux and gamma rays that penetrate the water, steel, and concrete shielding surrounding the core, and (3) streaming of neutrons and gamma rays through the HT-1 hole into the tank. For this case the tank was assumed void.

Attenuation factors. - In order to evaluate radiation levels at various locations around the loop, six energy group gamma ray attenuation factors were plotted for water, steel, and concrete. These attenuation factors, exclusive of geometry, include only buildup and absorption factors (refs. 5 and 6). The buildup factor was determined on an individual basis when attenuation through combinations of two or more materials was involved. Generally, the buildup factor was based on the total number of mean free paths through all materials. Where the last material before arriving at the point of detection was a thick region, the buildup factor was selected on a total mean free path basis. Where the last region was a thin sheet of metal, the buildup factor of the previous materials was used on a total mean free path basis. Concrete, aluminum, and water buildup factors are so similar that only a very small error exists, regardless of which material buildup factor is used, but steel and lead buildup factors differ greatly from these three materials and from each other. Therefore, material buildup factors were considered on an individual basis for each calculation, and where any real questionable combination was encountered, the conservative buildup factor was selected.

Fast neutron removal theory was used to describe neutron variations in water, steel, and concrete. Removal cross sections were obtained from reference 7. The neutron and gamma energy group breakdown are given in table VII. The results of these calculations are presented in figures 34 and 35.

Dose rate due to radiation through reactor shielding. - The dose rates at location A (fig. 33(b)) for both neutron and gamma radiation were determined in the original reactor design. The calculations in this section agreed with the reported values at this location by a factor of about 2. This is considered good agreement and indicates that the method of analysis is valid. The calculations were adjusted to agree with the reported values.

Concrete

HT-1

1500

900

200

200

45 75 450 600

20

75

450

45

Scale

3

2

1

0.28   1.5   8.5 Rad/hr   8.5   1.5 0.28 0

(a) Side view.

Shielding plug in place

A

200

45   8.5

1.5

0.28

0.05

0.0085

0.0015

B

1500

900

200   600

200

45 75   45

75

450   450

C
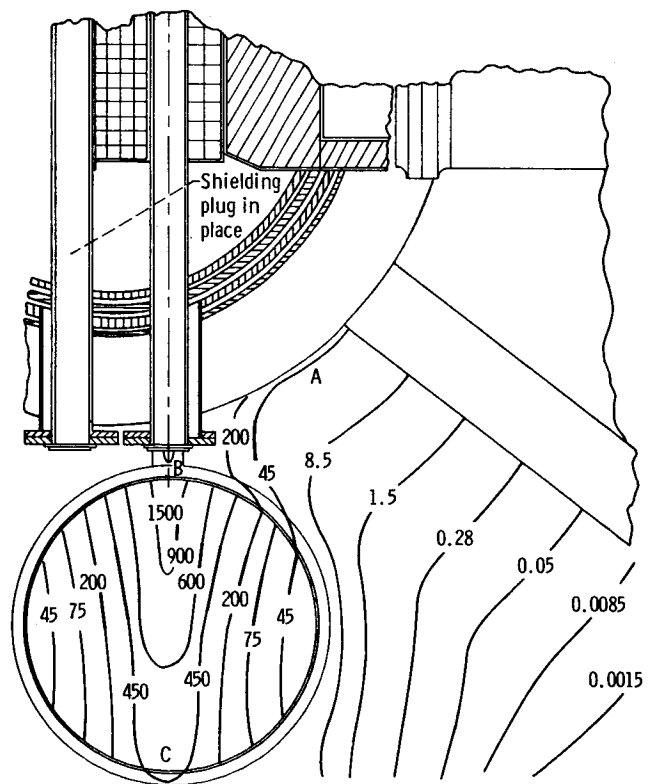
(b) Plan view.

Figure 33. – Isodose plot (rad/hr) of equipment tank.

79

(a) In water.

(b) In steel behind 2 feet of water.
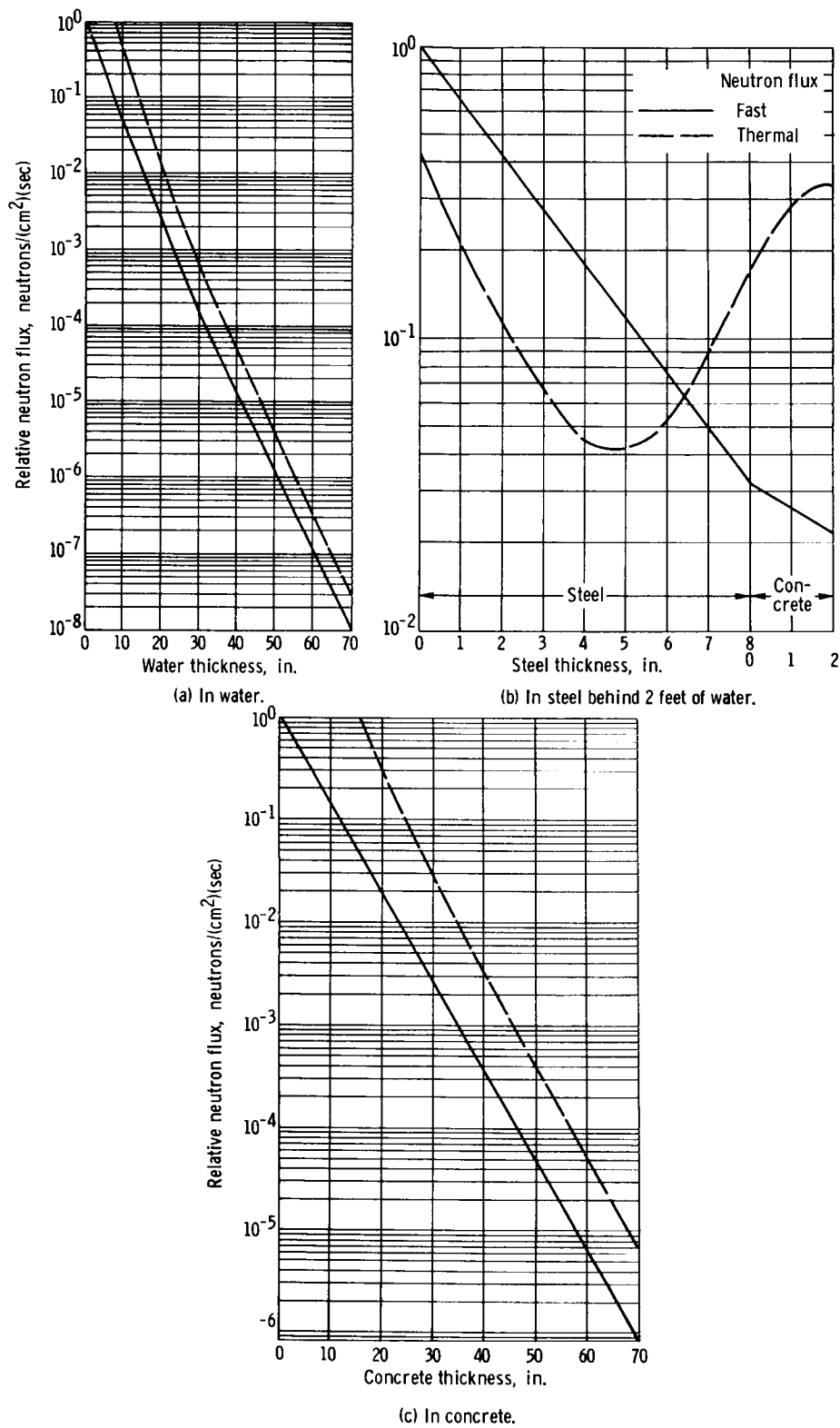
(c) In concrete.

Figure 34. – Fast and thermal neutron attenuation.
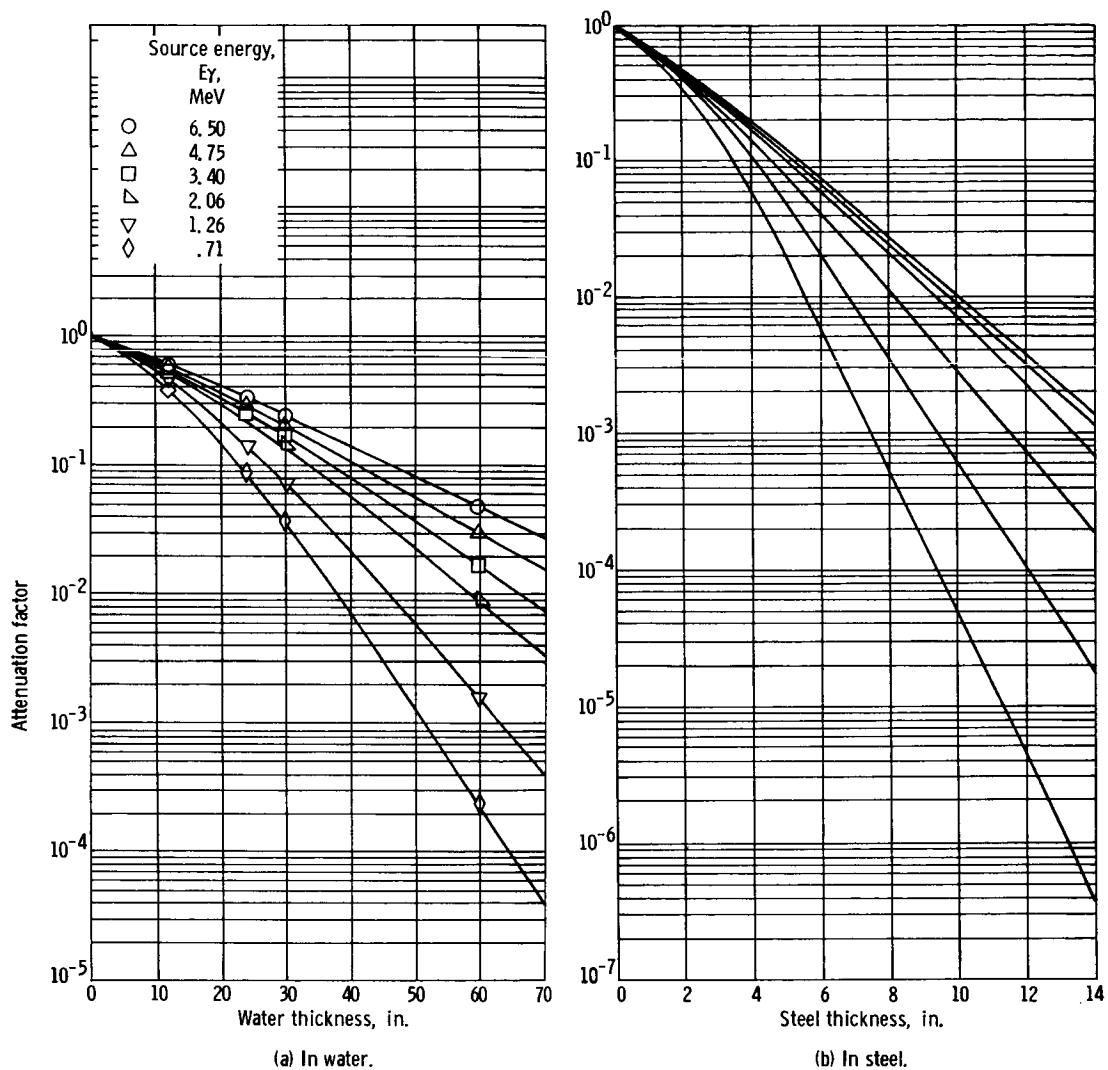
Figure 35. – Six group gamma attenuation factors.   Density, 7. 653 grams per cubic centimeter.

(a) In water.

(b) In steel.

Attenuation factor

Water thickness, in.

Steel thickness, in.

Source energy,
Eγ,
MeV

○   6. 50
△   4. 75
□   3. 40
◁   2. 06
▽   1. 26
◇   . 71
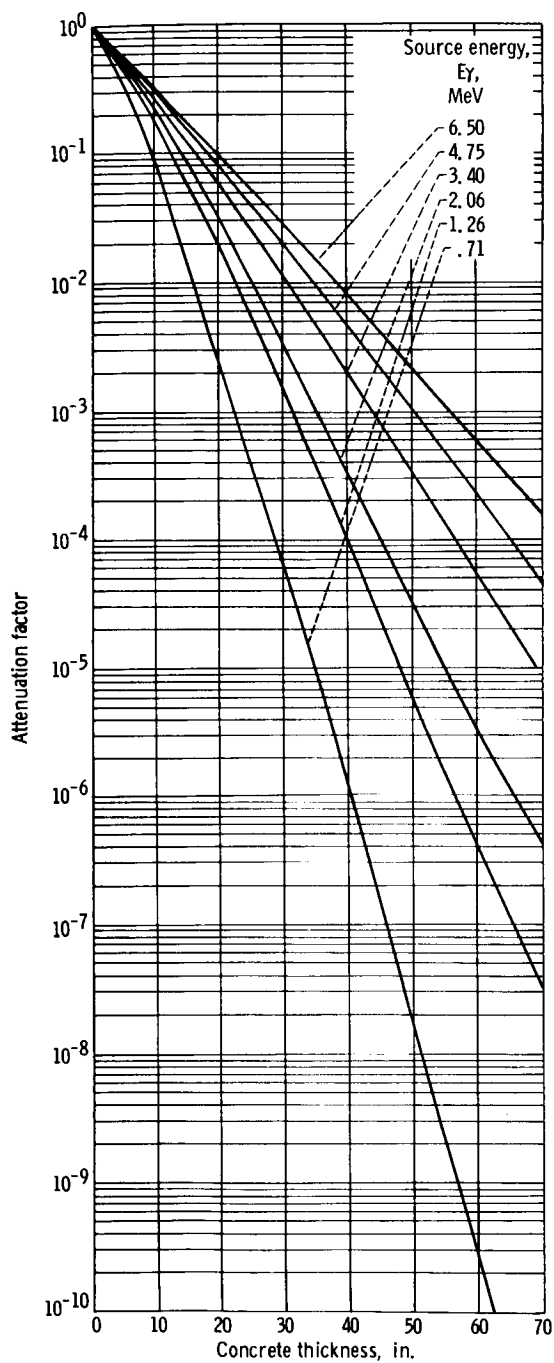
(c) In Portland concrete.

Figure 35. - Concluded.

TABLE VII. - NEUTRON AND GAMMA ENERGY

GROUP BREAKDOWN

	Effective energy, MeV	Energy range, MeV
Gamma group:		
I	6.50	5.50 - 10.00
II	4.75	4.25 - 5.50
III	3.40	2.76 - 4.25
IV	2.06	1.56 - 2.76
V	1.26	0.91 - 1.56
VI	0.71	0 - 0.91
Neutron group:		
Fast neutrons, φ_f	----	0.187 - 10.00
Thermal neutrons, φ_s	----	0.025 (eV) - 0.187

Dose rates due to neutron flux from reactor: Fast neutron removal theory was used to determine the fast neutron dose rates for the region shown in figures 33(a) and (b). The dose rates were calculated by using the following semiemperical expression taken from references 7 and 8:

$$\varphi_f = \frac{S_v R_o^2}{2}\left\{\frac{f\left[\theta_1\left(\Sigma_{s_1} Z_1 + \Sigma_i \Sigma_{i_1} t_i\right)\right]}{(r + Z_1)} + \frac{f\left[\theta_2, \left(\Sigma_{s_2} Z_2 + \Sigma_i \Sigma_{i_2} t_i\right)\right]}{8.27(r + Z_2)}\right\}$$

where

A_K atomic weight of Kth element in i^{th} shield region, $\int_0^{\theta_n} e^{-b} \sec \psi \, d\psi$

a_H weight fraction of hydrogen in i^{th} shield region

a_K weight fraction of Kth element in i^{th} shield region

$f(\theta_n, b)$ $\int_0^{\theta_n} e^{-b} \sec \psi \, d\psi$

h height of core, cm

n subscript differentiating use of two removal cross sections of hydrogen

R_o radius of core, cm

r distance from edge of core to detector, cm

S_v source strength, $n/(cm^3)$-(sec)

t_i thickness of ith shield region (water, steel, and concrete), cm

Z_n effective self-attenuation distance, cm

θ $\tan^{-1}\dfrac{h}{2(r + Z_n)}$

ρ_i density of ith shield region, g/cm^3

Σ_{i_n} macroscopic removal cross section of ith shield region,

$\rho_i N\left(\Sigma_k a_k \dfrac{\sigma_K}{A_K} + a_H \sigma_{H_n}\right)$, cm^{-1}

Σ_{s_n} macroscopic removal cross section of core, cm^{-1}

σ_{H_n} microscopic removal cross section of hydrogen in i^{th} shield region, $cm^2/atom$

σ_K microscopic removal cross section of Kth element in i^{th} shield region, $cm^2/atom$

φ_f neutron dose rate, neutrons/cm^2/(sec)

83

At location A (fig. 33(b)) the calculated dose rate is 3.07 rem per hour as compared with 1.6 rem per hour, the value reported in the original reactor design. The calculations were then adjusted to 1.6 rem per hour at location A. The relative biological effectiveness of fast neutrons is 10. Thus the dose rate in rads per hour at location A from the fast neutrons only is 0.16.

The thermal neutron flux was assumed to be 10 times the fast flux. Figure 34(c) shows a ratio of about 10 after 2 feet of concrete, the thickness of the concrete shield, has been penetrated. A dose rate of 1.6 rem per hour corresponds to a fast neutron flux of 1.6×10^4 neutrons per square centimeter per second and the corresponding thermal neutron flux is 1.6×10^5 neutrons per square centimeter per second.

Dose rates due to gamma flux from reactor: The following cylindrical source approximation was used to describe the core and beryllium sources (ref. 8); the sources are given in table VIII:

$$\varphi_\gamma = \frac{AS_v R_o^2}{2(a + Z)K}\left[f\ \theta, b(1 - \alpha)\right]$$

where

a   distance from surface of source to detector, cm

b $\Sigma \mu_i t_i + \rho_s Z$

f $\int_0^\theta e^{-b}\ \sec \varphi$, cm^{-1}

h   height of cylinder, cm

K   conversion factor between $Mev/(cm^2)(sec)$ and rem/hr

R_o radius of source, cm

S_v source intensity, $Mev/(cm^3)(sec)$

t_i thickness of ith shield region, cm

Z   effective self-attenuation distance

θ $\tan^{-1} \dfrac{h}{2(a + Z)}$

μ_i mass absorption coefficient for i^{th} shield region, cm^{-1}

μ_s effective mass absorption coefficient for source materials

A and α are constants associated with the exponential approximation to the dose

Radiation

Flow

Flow

Shield water
exit port

Aluminum inpile tube

Shielding
disk (typical)

Helium supply
and return lines

Shield water
inlet line
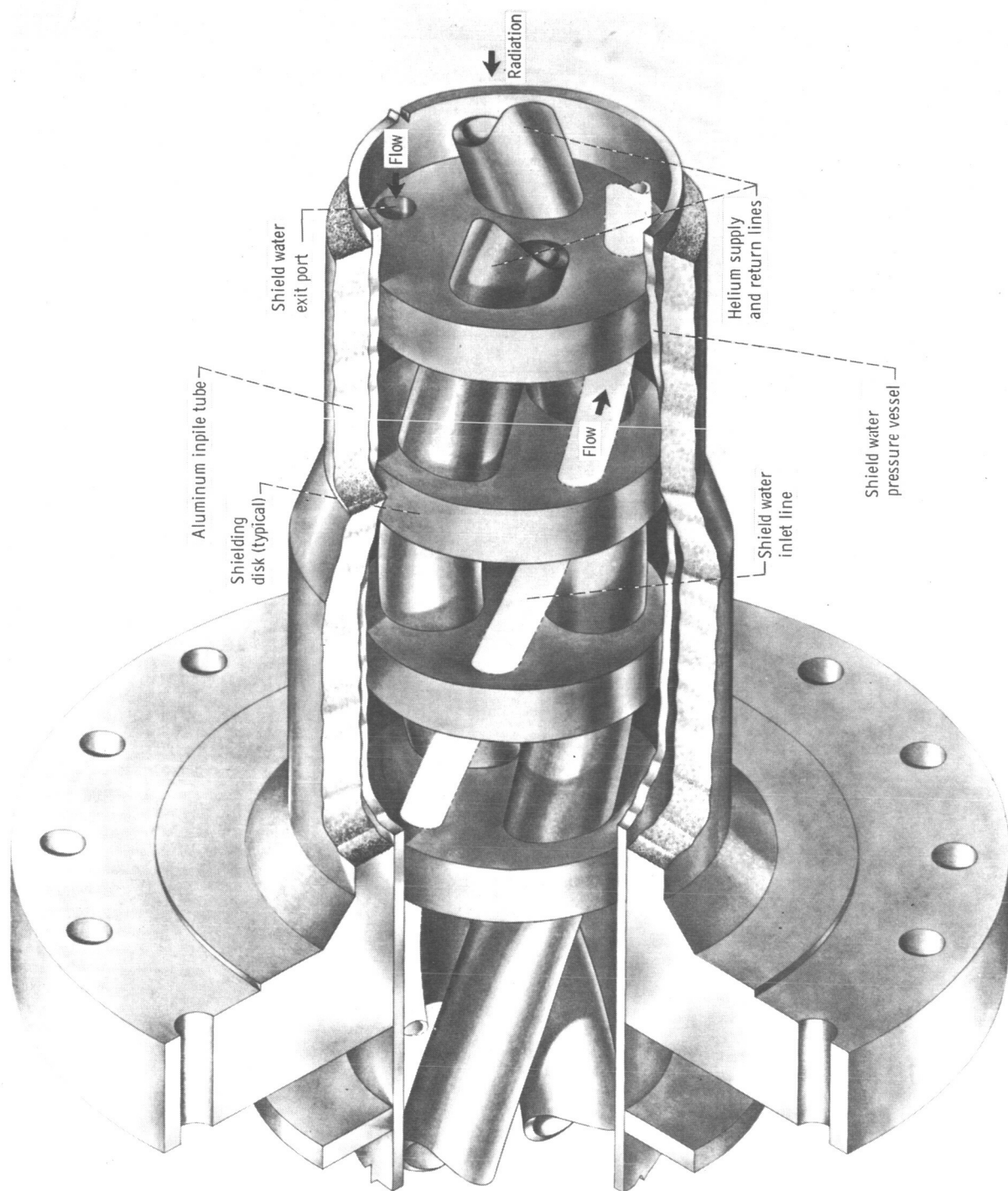
Shield water
pressure vessel

Figure 36. – Shielding configuration in inpile tube.

TABLE VIII. - CONE GAMMA AND

BERYLLIUM CAPTURE GAMMA

SOURCE SPECTRA

Group	Effective energy, MeV	Percent contribution
Core source		
I	6.50	5
II	4.75	5
III	3.40	19
IV	2.06	24
V	1.26	21
VI	.71	26
Beryllium capture gamma source		
I	6.5	60
III	3.4	40

buildup factor; that is, $B = Ae^{-\alpha\mu t}$, where μt is the number of relaxation lengths under consideration.

The dose rate distribution was then calculated for the region shown in figures 33(a) and (b). The reported value at location A, figure 33(b) is 45 rads per hour, and the calculated value agrees with this within a factor of 2. The calculations were then adjusted to agree with the reported value at location A.

Dose rates due to radiation streaming along HT-1 with inpile tube inserted. - In order to reduce streaming down the inpile tube, the helium lines passing through the water shield are formed into a spiral so that a straight streaming path down the helium lines is avoided. Additional shielding is provided by four 1.5-inch-thick steel disks in the water-pressure-vessel shield. A schematic showing the shielding configuration of the tubes and disks is given in figure 36. Because of the holes in these disks, the effective thickness of these four disks is 3.8 inches.

Neutron streaming: The fast neutron removal theory along with the standard neutron streaming equations were used to calculate the dose rates due to fast neutrons streaming into the equipment tank. The following equation was taken from references 6 and 9:

$$\varphi_f = \varphi_0 \frac{d^2}{8L} \left[1 + A \frac{\alpha^1}{(1 - \alpha^1)} + 2B \frac{d\alpha^1}{L(1 - \alpha^1)} \right] e^{-\Sigma_i \Sigma_{r_i} t_i}$$

where

A   fraction of wall scattering that is isotropic

B   fraction of wall scattering that is isotropic

d   effective diameter of streaming path, cm

L   length of duct, cm

t_i thickness of ith shield material in duct, cm

α^1 albedo of wall; assume $A + B = 1$, and the exponent 1 is of the order of 0.1 by experiment

φ_f fast neutron flux leaving duct, $n/(cm^2)(sec)$

φ_o fast neutron flux entering duct, $n/(cm^2)(sec)$

Σ_r fast neutron removal cross section of ith shield material in duct, cm^{-1}

The results of this calculation show a fast neutron flux of 6.0×10^4 and 2.0×10^4 neutrons per square centimeter per second at the front and rear, respectively, of the equipment tank (locations B and C, fig. 33(b)). Because of the water surrounding the area, a thermal to fast neutron flux ratio of 10 was assumed. Thus the thermal neutron flux at locations B and C are 6.0×10^5 and 2.0×10^5 neutrons per square centimeter per second, respectively.

Gamma streaming: The following gamma-ray streaming equation (refs. 6 and 9) was combined with gamma-ray attenuation factors and effective buildup factors to calculate the dose rates due to gamma rays streaming into the equipment tank:

$$\varphi_\gamma = \varphi^1 \frac{r^2}{2L^2} B_{eff} e^{- \Sigma_i(\mu_i t_i)}$$

B_{eff} effective buildup factor for total number of mean free paths in duct

L length of duct, cm

r radius of streaming path, cm

t_i thickness of ith shield material, cm

μ_i mass absorption coefficient for i^{th} shield material, cm^{-1}

φ_γ dose due to gamma rays, rem/hr

φ^1 gamma intensity entering duct, rem/hr

The use of the buildup factor in this way may introduce some conservatism into the analysis since the scattering volume is limited to the diameter of the streaming path at deep penetrations into HT-1.

The gamma scattering off the back wall (location C, fig. 33(b)) of the equipment tank was also considered. This was done by using the equation for scattering from a thick slab (refs. 5 and 10). The dose rates at points on the equipment tank wall out of the streaming path were found to be 100 to 1000 times lower in magnitude than the radiation incident upon the scattering surface.

The results of these and all the preceding calculations are given in figures 33(a) and (b).

Radiation Damage to Materials

Radiation damage to materials was evaluated by using the isodose curves shown in figures 33(a) and (b). It was assumed that the equipment tank was a void. Thus, the actual dose rates will be less than the calculated dose rates because of the shielding effects of the items in the equipment tank.

The total exposure time is 1300 hours, which is based on a 10-hour exposure once every 2 weeks over a 5-year period. Knowing the dose rate at a particular area and the exposure time, materials and equipment can be selected. Data were obtained regarding the radiation damage characteristics of various materials (ref. 11). On this basis, materials and equipment were selected.

Equipment Tank Activation

Equipment tank activation and dose rate calculations were performed by using the calculated neutron fluxes given in this appendix. The results of this calculation predicted radiation levels of less than 10 milliroentgens per hour at the surface after long exposure to the predicted neutron flux. From this it was concluded that contact maintenance would be possible on equipment in the tank as long as adequate shielding was provided for the inpile tube.

APPENDIX B

THERMAL AND STRESS ANALYSIS OF INPILE TUBE

Thermal Analysis of Inpile Tube

Inpile tube gamma heat generation rates. - In order to calculate the temperatures in the aluminum and steel pressure vessels of the inpile tube, the gamma heat variation in the reactor test hole (HT-1) with the inpile tube inserted must be known. Since experimental data are lacking, a computer program was used to obtain this information.

This program calculated the gamma heat profile along the centerplane of the reactor but did not give absolute values. The actual value at the point on the reactor centerplane closest to the core was experimentally determined to be 7.62 watts per gram. The calculated profile was then shifted to agree with the experimental data and is shown in figure 37(a). It should be noted that the program considers only the primary gamma rays originating in the reactor core. The secondary gamma rays originating in the beryllium and those streaming along the axis of HT-1 are ignored. This is not a serious limitation since only the gamma heat profile is of interest. Variation of the gamma heat along the axis of HT-1 was determined experimentally with HT-1 void and flooded. The results are shown in figure 37(b). It was assumed that the axial variation with the inpile tube inserted is the same as that when the test hole is flooded.

Inpile tube temperatures. - The temperatures developed in the aluminum and steel pressure vessels are a function of the gamma heating rates, the heat-transfer coefficients at the gas and water side, and the radial clearance between the aluminum and stainless steel pressure vessels.

The heat-transfer coefficients at both the gas and water side are calculated by using the following equation:

$$Nu = 0.023 \, Re^{0.8} \, Pr^{0.4} \tag{B1}$$

where

C_p heat capacity of fluid, Btu/(lb)(^{O}F)

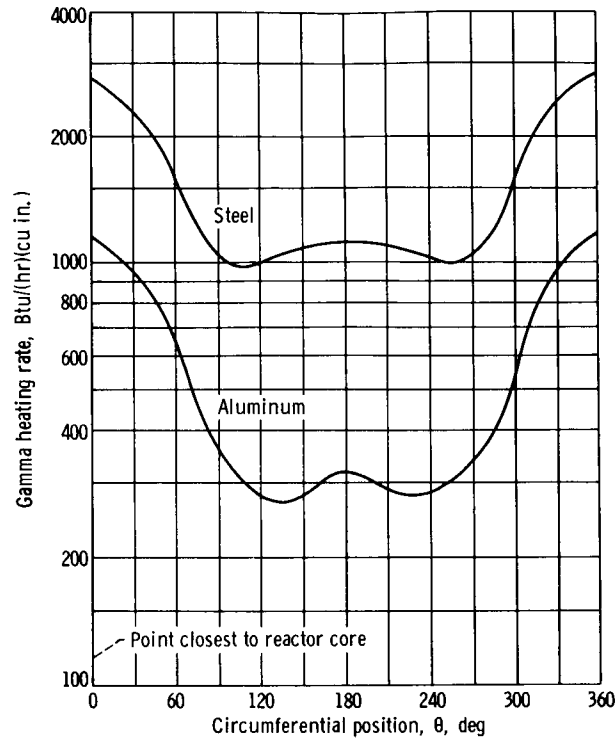d hydraulic diameter of flow path, in.

G mass velocity, lb mass/(sec)(in.^{2})
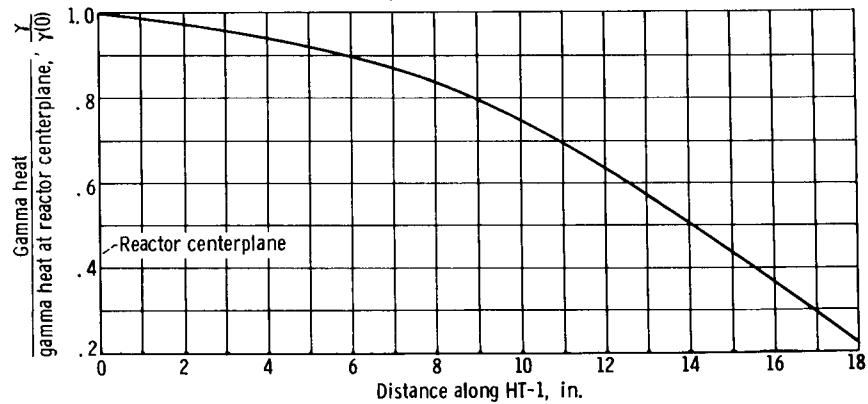
h film coefficient, Btu/(hr)(ft^2)(^{O}F)

K thermal conductivity, Btu/(hr)(ft)(^{O}F)

Nu Nusselt number, hd/K

Pr Prandtl number, μC_p/K

(a) Gamma heat profiles in circumferential direction.

(b) Gamma heat profile along axial centerline of flooded HT-1.

Figure 37. - Gamma heat profiles in steel and aluminum pressure vessels in HT-1 based on maximum of 7.62 watts per gram. Reactor power, 60 megawatts.

Re Reynolds number, Gd/μ

μ dynamic viscosity, lb mass/(ft)(hr)

The coolant water flow in HT-1 is 100 gallons per minute at an average bulk temperature of 140° F. The inside diameter of HT-1 and the outside diameter of the inpile tube are 9.000 and 8.442 inches, respectively. The physical properties were taken at the bulk temperature.

For the preceding conditions, a nominal water side coefficient of 1290.0 Btu/(hr)(ft^2)($^{\circ}$F) was calculated. The value of the film coefficient determined by equation (B1) can vary ±15 percent from nominal. To be conservative, a film coefficient 85 percent of nominal (1100.0) is used in subsequent calculations.

The helium flow through the test section may vary from 0.24 to 0.06 pounds second. The outside and inside diameters of the annular flow passage are 7.245 and 6.750 inches, respectively. At maximum flow, the Reynolds number is 16 350 at the inner wall of the steel pressure vessel. Thus, the flow is in the turbulent region. At minimum flow, the Reynolds number is 4087. Because of the irregular geometry at the inlet to the steel pressure vessel, the flow is assumed to be turbulent. The physical properties of helium were taken at an average bulk temperature of 257° F. This is the inlet temperature for a 100-kilowatt specimen.

For a flow rate of 0.24 pound per second, the nominal film coefficient is 117.0 Btu/(hr)(ft^2)($^{\circ}$F). A film coefficient 85 percent of nominal (110.0) is used in subsequent calculations. The film coefficient at a flow rate of 0.06 pound per second is 33.0 Btu/(hr)(ft^2)($^{\circ}$F).

To allow for assembly and disassembly, there is a radial clearance between the aluminum and steel pressure vessels of 0.0085 to 0.0165 inch. During operation, this gap is filled with stagnant helium.

In order to obtain a range of values, heat-transfer calculations were made for two cases:

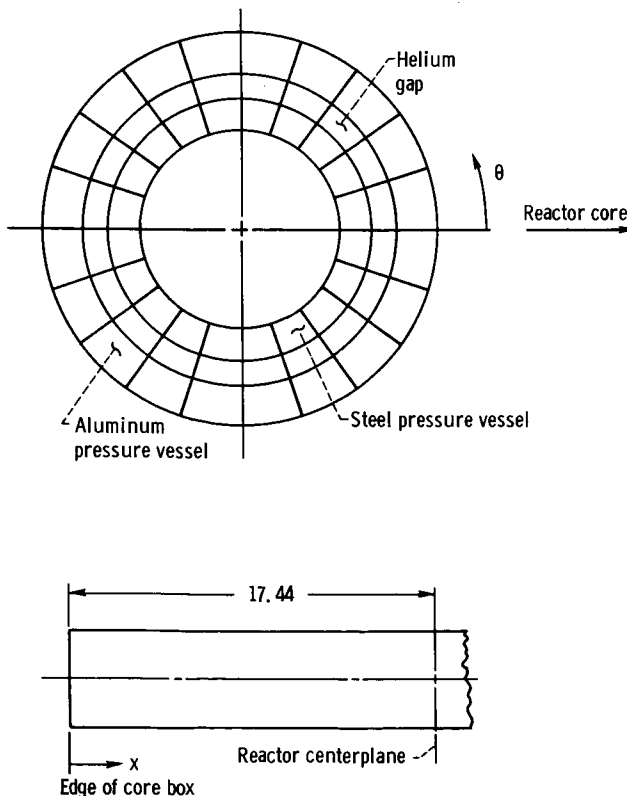Case 1: Minimum gap (0.0085 in.) and maximum helium flow

Figure 38. - Node pattern for inpile tube TOSS calculation.

$$h = 100 \left[\text{Btu}/(\text{hr})(\text{ft}^2)(^\text{O}\text{F}) \right]$$

Case 2: Maximum gap (0.0165 in.) and minimum helium flow

$$h = 33 \left[\text{Btu}/(\text{hr})(\text{ft}^2)(^\text{O}\text{F}) \right]$$

The heat-transfer calculations were made by using a computer code called TOSS (ref. 12). The inpile portion of the aluminum and steel pressure vessels were divided into a number of nodes for this code. The nodal pattern is shown in figure 38. Because the gamma heating rates are assumed symmetrical about the reactor centerplane, only one-half of the inpile portion was analyzed. The results for case 1 are shown in figure 39, and the results for case 2 are shown in figure 40.

Inpile Tube Stress Analysis

This analysis applies only to the portion of the inpile tube surrounding the test section and adjacent to the reactor core. The stress analysis of the shield water section is not given since it is not subjected to the severe operating conditions that the rest of the inpile tube experiences.

The maximum gamma heating rate in the inpile tube occurs on the reactor center-plane; thus the combined thermal and pressure stresses will be maximum in this region. In the inpile tube, the temperature varies around the circumference, through the thickness, and along the axis. It shall be shown that the maximum stress condition exists in the steel pressure vessel. The thermal stresses produced by the axial thermal gradient are trivial and can be ignored.

In the worst case (case 2), the inner pressure vessel has an axial and circumferential bending stress of less than 100 pounds per square inch. The corresponding stresses in the aluminum pressure vessel are even lower. Thus, in this analysis, only the temperature variation around the circumference and through the thickness shall be considered. The variation through the thickness is assumed to be linear.
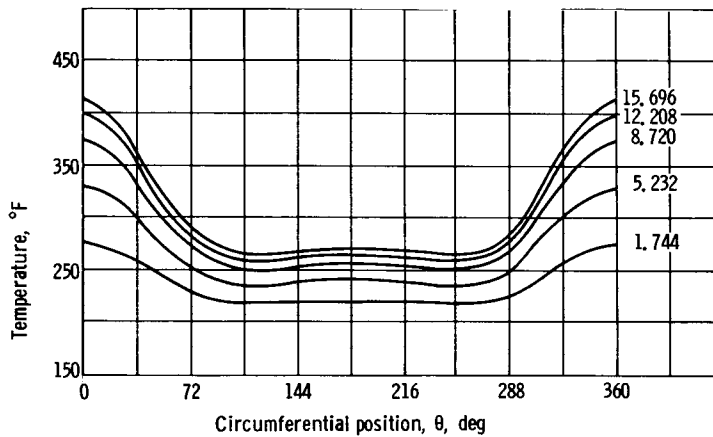
The axial thermal stress away from the ends is given by

$$\sigma_z = \frac{E\alpha}{2} \left[-(T_1 + T_2) \pm \left(\frac{T_1 - T_2}{1 - \mu} \right) + A_o + A_o' \right] \tag{B2}$$
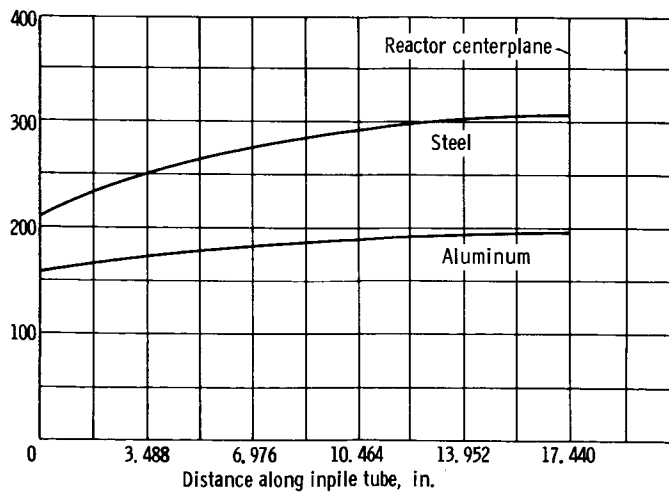
The tangential, or circumferential, bending thermal stress is given by
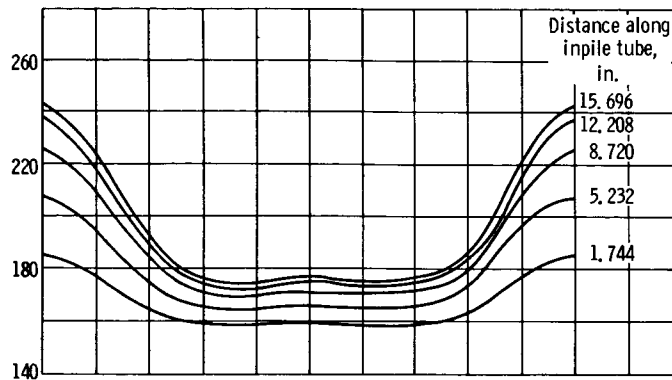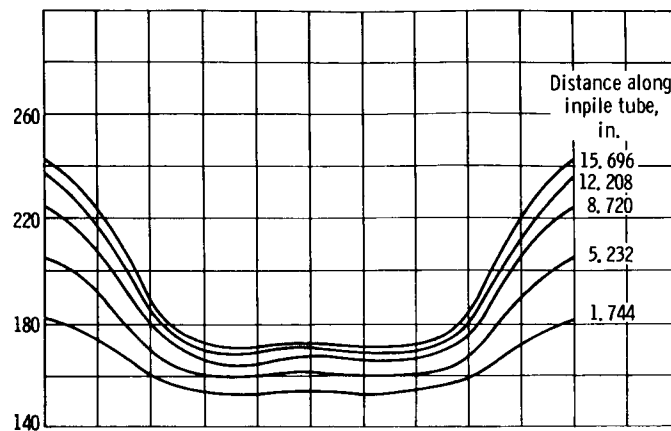
(a) Temperature of internal nodes for aluminum.

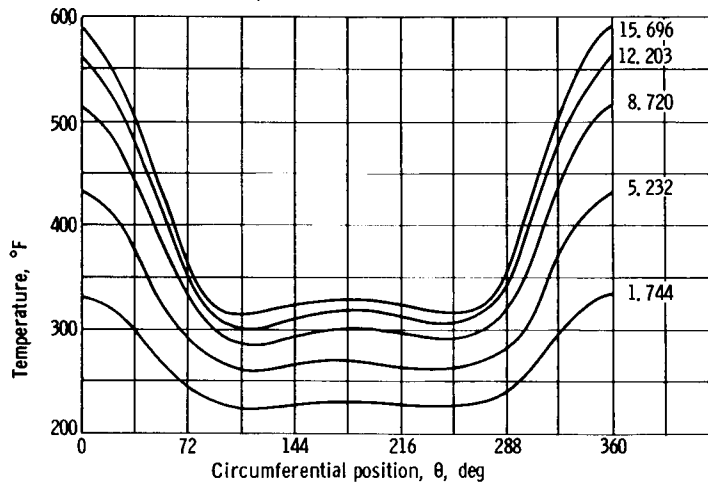(b) Temperature of internal nodes for steel.

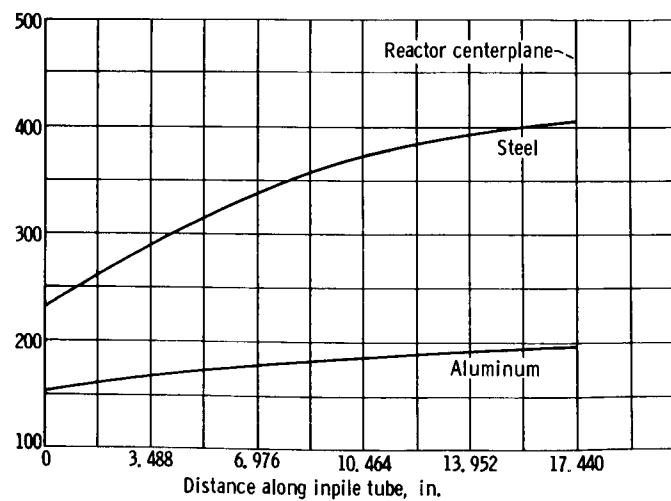(c) Average temperature of internal nodes for steel and aluminum.

Figure 39. – Temperature distribution of inpile tube for case 1 (minimum monitor gap and maximum helium flow).

(a) Temperature of internal nodes for aluminum.

(b) Temperatures of internal nodes for steel.

(c) Average temperature of internal nodes for steel and aluminum.

Figure 40. - Temperature distribution of inpile tube for case 2 (maximum monitor gap and minimum helium flow).

$$\sigma_t = \pm \frac{E\alpha(T_1 - T_2)}{2(1 - \mu)} \tag{B3}$$

where

A_o mean inside surface temperature, $^\circ$F

A_o' mean outside surface temperature, $^\circ$F

E   modulus of elasticity, psi

T_1 inside surface temperature, $^\circ$F

T_2 outside surface temperature, $^\circ$F

α coefficient of thermal expansion, in./(in.)($^\circ$F)

μ Poisson's ratio

σ_t tangential bending stress

σ_z axial thermal stress

In both of the preceding equations, the positive sign pertains to the outside. These equations are taken from reference 13.

There are pressure stresses in addition to the preceding thermal stresses. They are given by the following equations:

$$\sigma_z = \frac{P\overline{D}}{4h} \tag{B4a}$$

$$\sigma_t = \frac{P\overline{D}}{2h} \tag{B4b}$$

where

$\overline{D}$ mean outside diameter

h   wall thickness

P   pressure

The gamma heating and thus the temperatures are maximum at the reactor center-plane. A temperature map is not available for this location; thus, the temperatures at x = 15.696 inches (see fig. 38) will be used to calculate the thermal stresses. The

gamma heating at this location is about 97 percent of maximum; therefore, there is only a small loss in accuracy.

The modulus of elasticity E and the coefficient of thermal expansion α vary with temperature; thus, the following average values shall be used:

For 321 stainless steel:

$$E = 26.4 \times 10^6 \text{ psi}$$

$$\alpha = 9.59 \times 10^{-6} \text{ in. /(in.)}(^\circ F)$$

$$E\alpha = 253 \text{ psi/}^\circ F$$

$$u = 0.30$$

For 6061-T6 aluminum:

$$E = 9.5 \times 10^6 \text{ psi}$$

$$\alpha = 13.1 \times 10^{-6} \text{ in. /(in.)}(^\circ F)$$

$$E\alpha = 124.4 \text{ psi/}^\circ F$$

$$u = 0.33$$

Steel and aluminum pressure vessel stresses. - Table IX summarizes the stress analyses for the two cases mentioned previously in this appendix.

Evaluation of inpile tube stresses. - The design criteria are given in reference 1 (pp. 19-55). The material properties of 348 stainless steel are also given in this reference (Table N421 and Fig. N415(b)). The material properties of 6061-T6 aluminum are given in references 2 (p. 97) and 3 (p. 83). For the type of loading experienced by both pressure vessels, the maximum allowable combined stress is 3 times the design stress intensities given in the references cited.

The results of this evaluation are given in the section entitled Inpile tube temperatures and stresses (p. 24).

TABLE IX. - STEEL AND ALUMINUM PRESSURE VESSEL STRESSES

[The pressure stresses are assumed to be uniformly distributed across the pressure vessel wall; the maximum combined stress is at the inside diameter for both vessels.]

Pressure vessel stress	Case I: Minimum gap - maximum flow		Case II: Maximum gap - minimum flow	
	Vessel			
	Steel	Aluminum	Steel	Aluminum
Axial thermal stress, σ_z, psi:				
Outside diameter,	-29 200	-2 680	-51 800	-2 920
Inside diameter,	-25 000	-9 400	-49 000	-9 760
Tangential thermal stress, σ_t, psi:				
Outside diameter,	-2 160	3 340	-1 440	3 440
Inside diameter,	2 160	-3 340	1 440	-3 440
Inside surface temperature, T_1, °F	406	260	594	263
Outside surface temperature, T_2, °F	418	224	602	226
Mean inside surface temperature, A_0, °F	303	203	397	203
Mean outside surface temperature, A_0', °F	307	184	401	184
Axial pressure stress, σ_z, psi	3 890	-472	3 890	-472
Tangential pressure stress, σ_t, psi	7 780	-944	7 780	-944
Pressure, P, psi	227	-105	227	-105
Mean outside diameter, $\overline{D}$, in.	7.470	8.442	7.470	8.442
Wall thickness, h, in.	0.109	0.469	0.109	0.469
Combined stress, σ, :				
Outside diameter,	30 930	5 548	54 250	5 888
Inside diameter,	31 050	9 872	54 330	10 232

APPENDIX C

HELIUM PIPING PRESSURE DROP CALCULATIONS

For purposes of analysis, the piping will be divided into two parts: the cold side and the hot side. The cold side is defined as that part of the loop from the heat-exchanger exit (gas) to the inlet to the test specimen. The flow rate in this part of the loop is constant at 0.24 pound per second except for the portion from the junction of the main and bypass lines to the test specimen inlet. The flow in the main line from the junction to the test specimen inlet can vary from 0.06 to 0.24 pound per second. The flow in the bypass line can vary from zero to 0.18 pound per second. The hot side of the loop is defined as that part of the loop from the mixing point in the inpile tube of the two gas streams to the heat-exchanger inlet (gas). The flow rate in the hot side is constant at 0.24 pound per second. A schematic of the piping is given in figure 8.

The following equation gives the frictional pressure loss in the piping:

$$\Delta P = \frac{4fG^2 VL}{2g_c D_e} \tag{C1}$$

where

D_e hydraulic diameter

f   Fanning friction factor, $0.079 \, Re^{-0.25}$

G   mass velocity, lb mass/ft^2 sec

g_c 32.2 ft lb mass/lb force (sec^2)

L   length of flow path, ft

ΔP pressure loss, psi

Re   Reynolds number, $\rho_v D_e / \mu$

V   specific volume, ft^3/lb mass

v   velocity, ft/sec

μ dynamic viscosity, lb mass/(ft)(sec)

ρ density, lb mass/ft^3

All calculations are based on the information given in table X. Data for the equivalent straight length of fittings are taken from reference 14.

TABLE X. - LOOP OPERATING CONDITIONS

Parameter	Power, kW			
	130		230	
	Cold side	Hot side	Cold side	Hot side
Average pressure, psia	188	177	213	203
Average temperature, $^\circ$F	210	577	312	1000
Viscosity, μ, $lb_{mass}/(ft)(sec)$	1.50×10^{-5}	2.02×10^{-5}	1.65×10^{-5}	2.53×10^{-5}
Specific volume, V, ft^3/lb_{mass}	9.55	15.70	9.72	19.29

Cold-Side Pressure Drop Calculations

The flow rate is constant (0.24 lb/sec) from the heat-exchange exit to the junction of the main and bypass lines. The pipe size is also constant (2.067-in. i.d.), and the equivalent length of the flow path is 21.57 feet. The calculated pressure drops for a system heat load of 130 and 230 kilowatts are 0.23 and 0.24 pound per square inch, respectively. Note that the pressure drop varies little with system heat load, so this variable will be ignored in the remaining calculations for the cold side.

In the remaining portion of the cold side (from the junction of the main and bypass lines to the inlet to the test specimen), the flow can vary from 0.06 to 0.24 pound per second. The pressure drop in the bypass line is not considered since this line is parallel with the remaining portion of the cold side (see fig. 8, p. 12).

For purposes of analysis, the remaining portion of the cold side is divided into the following three sections:

(1) Main line from junction point to inlet to inpile tube

(2) Helixed line in shield water pressure vessel

(3) Test section pressure vessel

A brief description of each section follows, and the results of the calculations are given in table XI.

Section 1. - This line is located in the equipment tank and includes valve V-101 and flowmeter F-147. The pressure losses in these items are considered separately. The inside diameter of the line is 2.067 inches.

Section 2. - The flow passage in this section is annular with an outisde and inside diameter of 2.245 and 1.125 inches, respectively.

Section 3. - Because of the irregular geometry and the rapid change in flow areas at the inlet and exit, the conventional equations for pressure change due to expansion and contraction do not apply; thus, only the pressure loss due to friction in the annulus is

TABLE XI. - COLD SIDE PRESSURE

DROPS FOR SECTIONS 1, 2, AND 3

Section	Equivalent length of flow path, ft	Flow rate, lb/sec	
		0.24	0.06
		Pressure drop, psi	
1	25.80	0.28	0.02
2	7.75	.22	.02
3	2.58	.15	.01

calculated. This also will be somewhat in error due to the irregular flow pattern in the inlet region. The outside and inside diameters of the annulus are 7.245 and 6.750 inches, respectively.

Hot-Side Pressure Drop Calculations

The flow rate and pipe size in this part of the loop are constant at 0.24 pound per second and 2.067-inch inside diameter, respectively, and the equivalent length of the flow path is 34.7 feet for system heat loads of 130 and 230 kilowatts. The calculated pressure drops are 0.66 and 0.86 pounds per square inch, respectively.

Summary of Pressure Drop Calculations

The calculated friction pressure drops in the piping and the drops in the various items in the circuit are summarized in table XII. The values given for the filter and heat exchanger are the maximum allowable losses for these items.

Thus, all the losses in the helium system, with the exception of the throttle valves V-101, V-102, and the test specimen, are accounted for. The pressure drop across the throttle valves varies with flow rate and valve stem position. The pressure drop across the test specimen is a function of flow rate and geometry.

TABLE XII. - HELIUM PIPING

PRESSURE DROPS

Helium piping	System heat load, kW	
	130	230
	Pressure drop, psi	
Pipes and fittings	[a]1.55/0.95	[a]1.75/1.15
Flowmeter F-146	0.25	0.25
Flowmeter F-147	0.25/0.03	0.25/0.03
Filter	0.40 (max.)	0.40 (max.)
Heat exchanger	2.50 (max.)	2.50 (max.)
$\sum \Delta P$, psi	[a]4.95/4.13	[a]5.15/4.33

[a]Maximum and minimum pressure drops are
for maximum and minimum helium flow
through the test section.

APPENDIX D

TEMPERATURE CONTROLLER TESTS

Open-Loop Transfer Function Measurement

Electrically heated tests were conducted to analyze the stability of the loop control system by measuring the open-loop transfer function at various operating conditions. From the analysis of the transfer function data, controller adjustments were determined and further electrically heated test runs were made in the automatic mode of control to demonstrate the stability of the controller.

Test Equipment

Heating element and assembly. - The heating element is a resistance heater made of four Nichrome V plates welded together in a series-parallel configuration. The heater was designed to simulate the surface area, the cross-sectional area of the flow passage, and the heat capacity of a proposed 50-kilowatt test specimen model. Nichrome V was selected for the plate material because it gave the proper heater resistance to match the voltage and current characteristics of the power source. The heater is mounted in a split boron nitride insulator. The power is supplied to the heater through four water-cooled copper electrodes that are attached to the upstream end of the heating element. This test assembly is instrumented with five Chromel-Alumel thermocouples: one for inlet gas temperature, one for exit gas temperature, and three for heating element surface temperature. There are also pressure taps for measuring test element differential pressure. The heater and assembly are shown in figure 41.

Power source. - The power source used has a rated output of 3000 amperes at 40 volts of direct current. It can be operated in three modes of control: manual, remote, and set point. For these tests, the supply was operated in the set-point mode. In set-point mode, this power source will supply a regulated current of desired magnitude to the load by manually setting a 10-turn helipot on the power source control panel. The dial of this control is calibrated from 0 to 100, which corresponds to 0 to 100 percent of the maximum output current (4000 A). Set-point dial settings were recorded in the data along with voltage and current readings at various power levels.

Test instruments. - The test instrumentation consited of the following: two wide-band differential direct-current amplifiers, a low-frequency function generator, a 14-channel recording oscillograph, a digital voltmeter, three direct-current power supplies, and a test panel. The test panel provided the connectors and voltage control
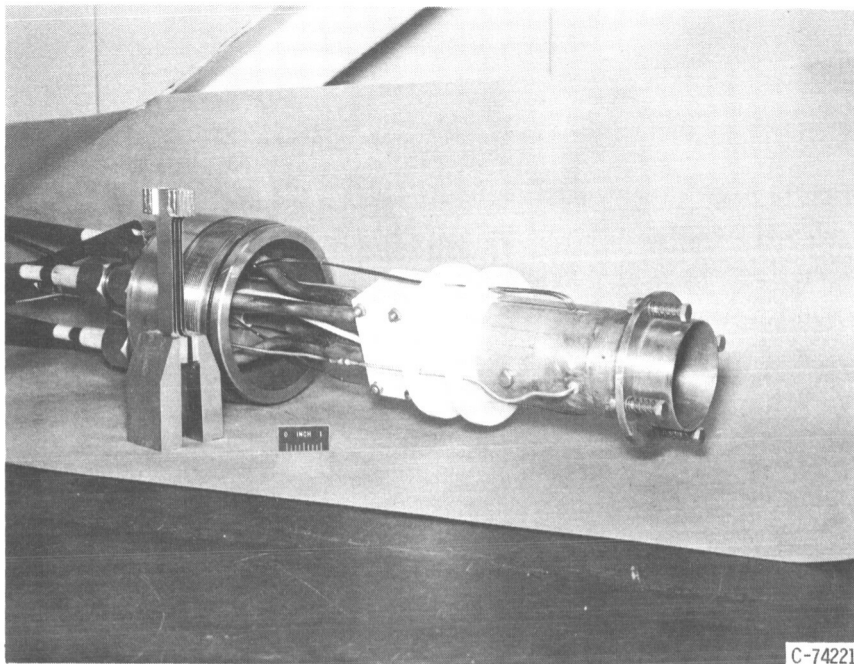
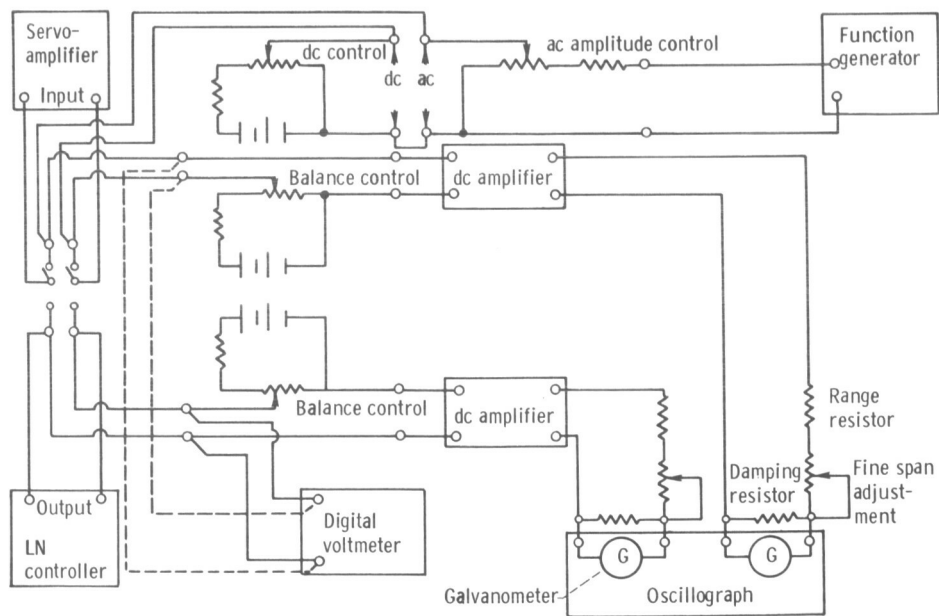Figure 41. – Heater element and assembly.

Figure 42. – Test instrumentation for transfer function measurement.

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TABLE XIII. - OPERATING CONDITIONS

	Run		
	1	2	3
Temperature rise across test element, $^{\circ}$F	160	200	140
Helium pressure P-103, psia	201	180	172
Helium temperature T-121, $^{\circ}$F	200	180	178
Test element flow, lb/sec	0.148	0.144	0.174
Heater power, kW	31.4	30.91	31.23
Proportional band setting, percent	4	7	4

TABLE XIV - RESULTS OF OPEN-LOOP

TRANSFER FUNCTION TESTS

Run	Open loop gain at 180° phase shift, db	180° phase-shift frequency, rad/sec
1	-15	3.5
2	-16	3.8
3	-17	4.2

potentiometers for the alternating- and direct-current components of the test signal as well as the connectors and direct-current balance controls for each amplifier. The test instrumentation circuitry is given in figure 42.

Test procedure and results. - The open-loop transfer function was measured in the following manner for the conditions listed in table XIII. With the controller in the manual mode of operation, the control loop was opened between the controller and servoamplifier, and a simulated control signal was switched to the input of the servoamplifier. The controller was then switched to the automatic mode, and a sinusoidal perturbation of a known frequency was added to the direct-current control signal. The perturbations were varied over a range of frequencies. The input and output signals were recorded on an oscillograph. By comparing the input and output traces, the gain and phase shift were determined.

Table XIV gives the results of three test runs, and figures 43 and 44 show the plots of gain and phase shift against perturbation frequency.

Controller Reset Rate

The reset rate was determined by the following criterion:

$$\text{Reset rate} = 0.19\ W_{\mu}$$

where W_{μ} is the 180° phase-shift frequency. The values of W_{μ} are from table XIV
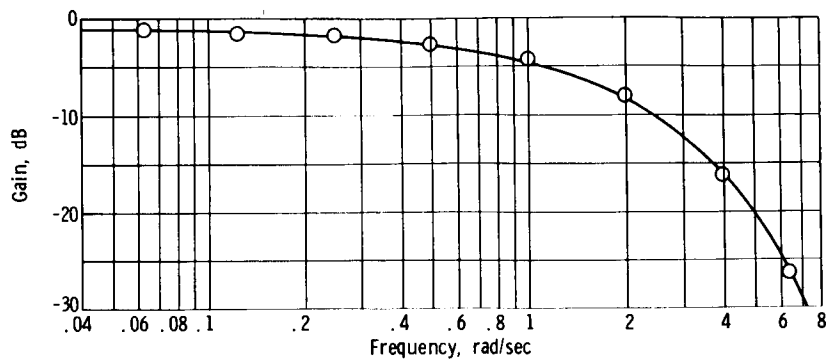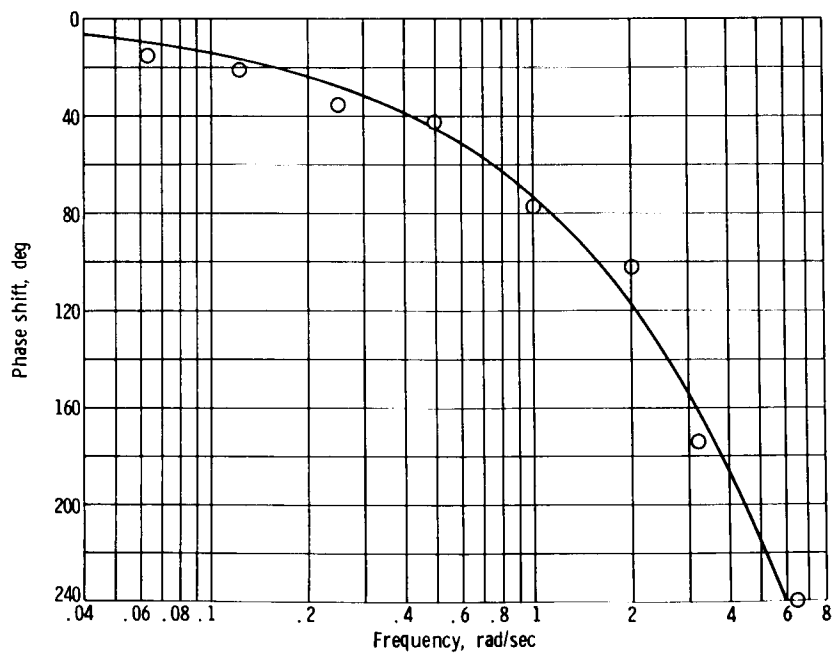
Figure 43. – Open loop gain. Run 2.

Figure 44. – Open loop phase shift. Run 2.

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and from a theoretical analysis. With these values, the resulting reset rates range from 25 to 47 resets per minute with an average value of 39 resets per minute. The settings for the reset rate dial are rather coarse in this region; therefore, the dial was set at 30 resets per minute, the closest setting to the average value. This reset rate setting was used for the step response tests that follow.

Step Response Test

The purpose of this test was to demonstrate the ability of the controller to provide stable control action and to observe the transient response of such loop variables as test element flow, test element plate temperatures, and test element exit gas temperature.

The test was conducted at the following steady-state conditions and with the controller initially in the manual mode of operation: temperature rise across test element, 160° F; test element flow, ~0.18 pound per second; test element power, ~30 kilowatts. The controller was switched to the automatic mode, and step changes of about 20° F in control point were made at the controller for various proportional band (PB) settings.

(a) Proportional band setting, 6 percent.

(b) Proportional band setting, 4 percent.
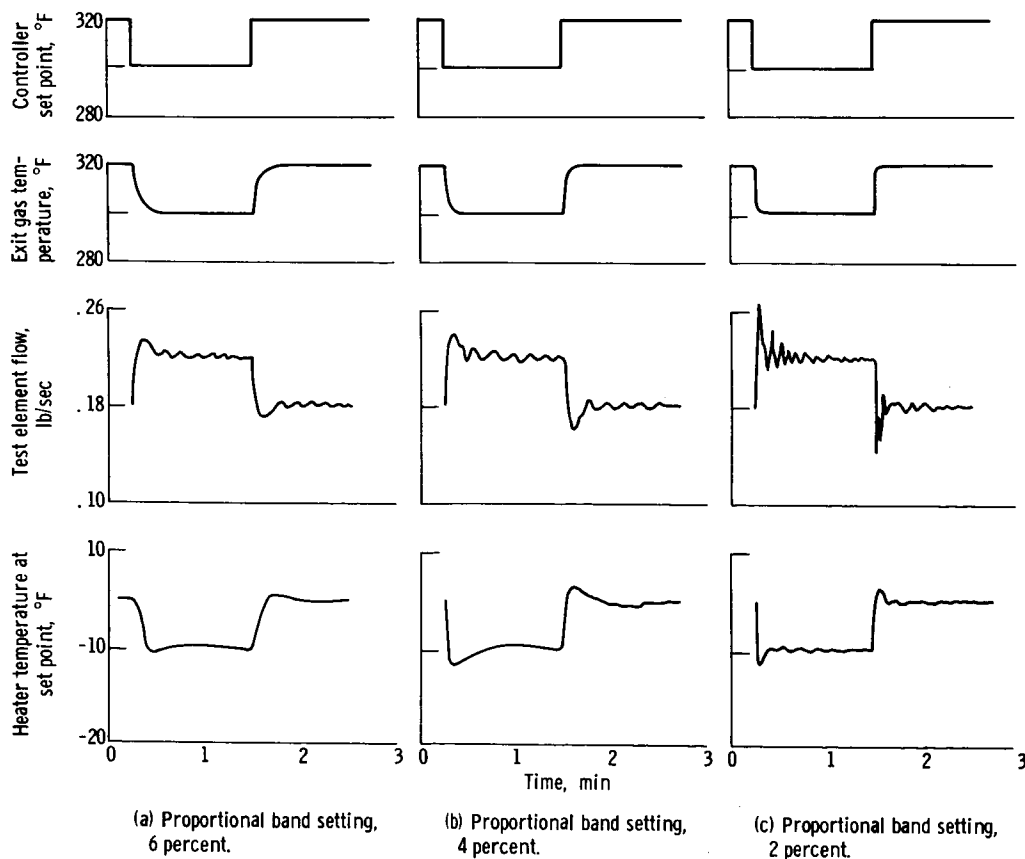
(c) Proportional band setting, 2 percent.

Figure 45. - Step response test.

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The following system variables were recorded: test element exit gas temperature (T-1) (T-129), test element flow (F-147 and F-147A), and test element plate temperatures. Figure 45 shows the response of these variables as a function of time. The change in control point is also shown.

Conclusions

In order for a closed-loop control system to be stable, the open-loop gain must be less than 1.0 for a phase shift of 180°. From the data given in table XIV, it can be seen that this stability criterion is met.

The step response test (fig. 45) shows that the controller is providing control action. When the controller set point is stepped to a lower value, the test specimen exit gas temperature (T-129) drops to the new set point, the test element flow increases (F-147 and 147A), and the test specimen plate temperature decreases. The test specimen power remained constant.

Figure 45 shows that, as the proportional band (PB) is made narrower (gain increased), the test specimen exit gas temperature follows the changes more quickly. However, spikes begin to appear in the test element flow response, especially at the leading edge. As the PB decreases, the magnitude of the spikes increases, and a scram could be initiated if the loop is operating close to a scram set point (high or low). Therefore, the response of the test specimen exit gas temperature is limited by the minimum PB setting for which no large spikes in the flow response occurs.

Because the step response test was so successful in determining the proportional band setting, a push-button-operated step in control point of approximately 15° F was incorporated in the controller to determine the proper setting during an actual test run.

APPENDIX E

CALIBRATION OF LOOP PRESSURE TRANSDUCERS

Purpose

Each pressure transducer used in the loop was tested to determine linearity, hysteresis, and the 100 percent R_{cal} resistor. Excitation voltages and amplifier gain settings were also determined as a result of these tests.

Procedure

Each transducer was electrically connected to the instrument channel in which it was to be used. Just prior to calibration each transducer was pressure cycled three times from zero to 100 percent of its range. During the third cycle, the instrument was zero balanced, and its full-scale output adjusted. Pressure was then applied in steps of 20 percent of full scale, starting at zero and increasing to full scale and then decreasing in equal steps back to zero. The applied pressures were measured by standard gages and and/or by manometer tubes.

The output readings were read directly from recorders on the loop instrument console for channels using recorders. A digital voltmeter was used to monitor the data-logger outputs for channels using strain-gage amplifiers.

Results and Conclusions

Table XV lists the data and results for two typical transducers. The values listed in the computed-output column are for a linear output against pressure curve, which passes through the average of the two measured zero pressure output readings and the measured full-scale output reading. The correction is the difference between the measured and computed outputs. The nonlinearity is the percent of full scale represented by the maximum correction. The amount of hysteresis is the difference between output readings observed when the pressure was increased and decreased at a given pressure level. The percent hysteresis is the percent of full scale of the maximum difference.

Since these tests included the amplifiers and recorders used in reading out the various pressures, the nonlinearities measured were the total combined nonlinearities in each instrument channel. All channels read within their expected accuracy.

TABLE XV. - DATA AND RESULTS

(a) Variable, P-501; amplifier 8; range, 0 to 15 psia; excitation voltage, 4 V (root mean square); coarse gain, high; transducer serial number, 10901; zero unbalance, 0.22 percent; nonlinearity, 0.24 percent; hysteresis, 0.11 percent; calibrating resistor R_{cal} (100 percent), 47 130

Applied pressure, psia	Data logger output	Computed output	Correction	Hysteresis
0	0.00022	0.00021	-0.00001	0.00002
3	.02011	.02015	+.00004	.00002
6	.04013	.04009	-.00004	.00003
9	.06002	.06003	+.00001	.00011
12	.08021	.07997	-.00024	.00008
15	.09980	.09980	--------	-------
12	.08000	.07997	-.00003	-------
9	.06013	.06003	-.00010	-------
6	.04016	.04009	-.00007	-------
3	.02009	.02015	+.00006	-------
0	.00020	.00021	+.00001	-------

(b) Variable, P-201; amplifier 7; range, 0 to 200 psia; excitation voltage, 4 V (root mean square); coarse gain, low; transducer serial number, 10899; zero unbalance, 12 percent; nonlinearity, 0.94 percent; hysteresis, 0.0009 percent; calibrating resistor R_{cal} (100 percent), 17 230

Applied pressure, psia	Data logger output	Computed output	Correction	Hysteresis
0	0.00011	0.000115	+0.000005	0.00001
40	.02095	.020094	+.000001	.00005
80	.04101	.040073	+.000937	.00012
120	.06094	.060052	-.000898	.00002
160	.08052	.080031	-.000489	.00009
200	.10010	.10010	---------	-------
160	.08061	.080031	-.000579	-------
120	.06092	.060052	-.000868	-------
80	.04089	.040073	-.000717	-------
40	.02090	.020094	-.000806	-------
0	.00012	.000115	-.000005	-------

APPENDIX F

FLOWMETER CALIBRATION

Purpose

Heat generated by the test specimen will be determined primarily from coolant mass flow and temperature rise; therefore, an accurate mass flow rate is desired. To measure the helium coolant flow, venturi flow tubes were chosen for the loop installation (fig. 46). Because of space limitations, it was impossible to condition the flow with sufficient straight lengths of pipe immediately before and after the flowmeter (fig. 47).

Available calibration curves for commercial meters are for conditioned flow; therefore the actual meters were calibrated after they were installed. The loop equipment was used to provide the helium flow for the calibration.
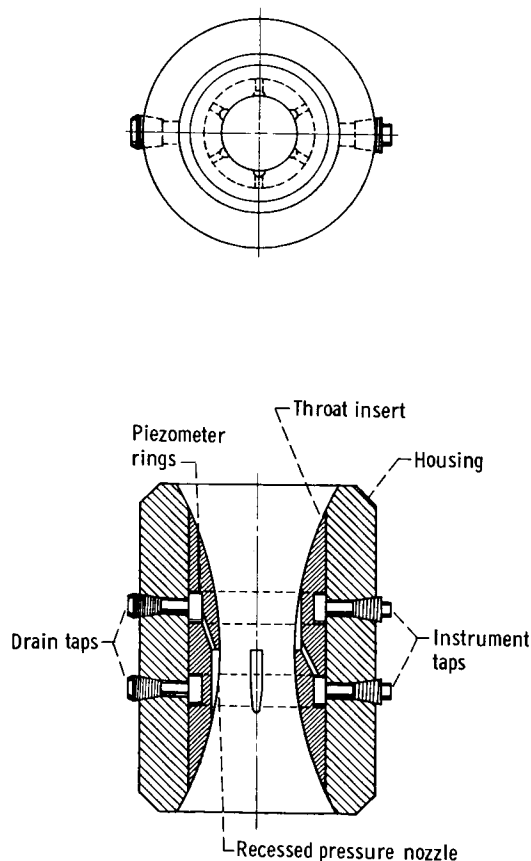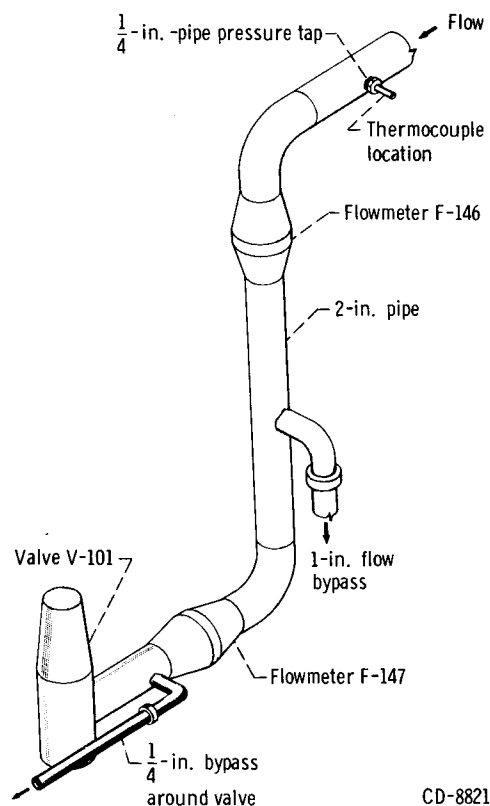
Figure 46. - Flowmeter.

Figure 47. - Piping assembly for flow calibration.

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Method

The basic equation used for the mass flow calculation was developed from information from references 15 and 16:

$$w_s = F_a F_R K_\infty Y_a \; 0.5250 \; d_2^2 \; \sqrt{\Delta p \gamma} \qquad (F1)$$

where

d_2 flow tube throat diameter, in.

F_a area factor for thermal expansion of the primary element

F_R flow coefficient at infinite Reynolds number, includes velocity of approach factor

Δp differential pressure across primary element of F-146 and F-147, psi

w_s rate of flow, lb/sec

Y_a expansion factor for venturi tubes

γ upstream specific weight, lb/cu ft

The object of the calibration of the two flowmeters, F-146 and F-147, was to get the quantity $0.5250 \; F_R K_\infty d_2^2$ for the equation (F1) for each meter as a function of the pipe Reynolds number. This quantity, called the meter constant, is obtained by solving equation (F1) explicitly and either measuring or calculating the unknown quantities in the right-hand side of the equation.

The mass flow w_s is measured by the standard orifice meter, which is a 2-inch VDI (verein deutscher ingenieure) concentric orifice that was inserted into the straight-line run out of filter F-105, as shown in figure 48. The accuracy of this measurement is approximately ±0.25 percent. The range of the parameters covered in the calibration tests is given in table XVI.

TABLE XVI. - RANGE OF TEST CONDITIONS

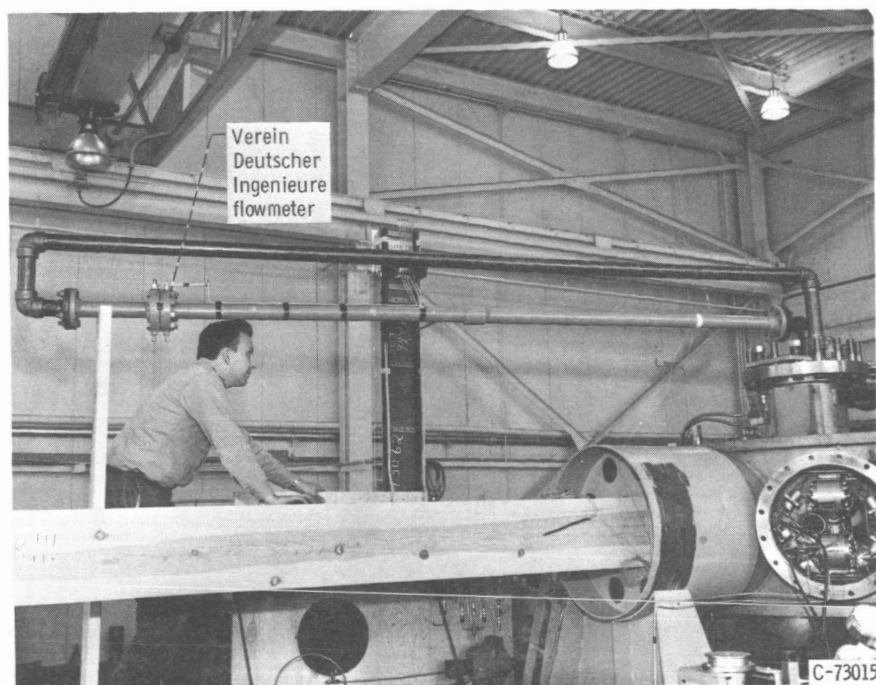| Run	Condition	
	First set	Second set
Helium flow range, lb/sec	0.0799 - 0.2534	0.09574 - 0.25453
Helium pressure (P-103), psia	156.7	194.6 - 192.2
Density, lb/cu ft	0.1028 - 0.1089	0.1103 - 0.1197
Reynolds number, R_D	40 011 - 130 713	44 150 - 123 665
Temperature (T-121), °F	162 - 126	245 - 182
Viscosity, μg, lb/(sec)(ft)	$149{\times}10^{-7}$ - $143{\times}10^{-7}$	$162{\times}10^{-7}$ - $152{\times}10^{-7}$

Figure 48. – Installation of Verein Deutscher Ingenieure flowmeter.

During calibration both the differential pressure ΔP and the upstream specific weight γ are obtained with auxiliary instrumentation. The differential pressure was measured with an accuracy of 0.1 percent of the reading. The specific weight for each flowmeter is computed from the gas laws from a measurement of upstream temperature and static pressure. The temperature was measured with an approximate accuracy of 0.1 percent of the reading and the pressure with an approximate accuracy of 0.15 percent of the reading.

The remaining factors needed to complete the calculation of the calibration coefficient are F_a and Y_a. Factor F_a from the curve for 304 stainless steel in figure ure C-2-1 of reference 16, was used to compensate for the thermal expansion of the primary element. The factor Y_a for a gas is obtained from the following equation for isentropic flow (ref. 5):

$$Y_a = \left[r^{2/k}\left(\frac{k}{k-1}\right)\left(\frac{1 - r^{k-1/k}}{1 - r}\right)\left(\frac{1 - \beta^4}{1 - \beta_r^{1/k}}\right) \right]^{1/2} \tag{F2}$$

where

k   ratio of specific heat at constant pressure to specific heat at constant volume for helium (1.67)

r   ratio of throat static pressure drop to pipe static pressure, $\Delta p/p$

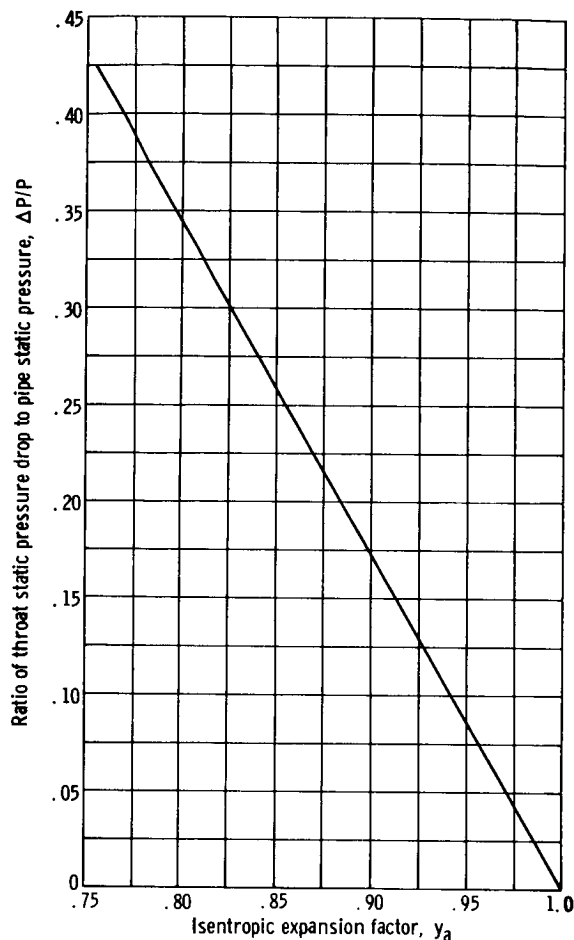β ratio of throat to pipe diameter, $d/D = 0.5138$

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Figure 49. - Isentropic expansion factor as function of static pressure ratio for venturi flow tubes. Ratio of specific heat at constant pressure to specific heat at constant volume, 1.67; ratio of throat to pipe diameter, 0.5138.

A plot of Y_a against r is presented in figure 49. For the 100-kilowatt-fueled experiment, all $\Delta p/p$ values will be below 0.0075, and an inspection of figure 49 shows that $Y_a(\Delta p/p)$ is a straight line function over this limited range.

The pipe Reynolds number is determined from the following equation:

$$R_D = \frac{48}{\pi D \mu g} w_s = 7.392 \frac{w_s}{\mu g} \qquad (F3)$$

where

g 32.17, $\mathrm{ft/sec}^2$

μ viscosity of fluid, $\mathrm{lb\text{-}sec/ft}^2$

RESULTS AND DISCUSSION

Compressibility effects are demonstrable by plotting

$$\frac{w_s}{F_a \sqrt{\Delta p \gamma}} = 0.5250 \, F_R Y_a K_\infty d_2^2$$

against acoustic ratio for flow tubes F-146 and F-147 (figs. 50(a) and (b), respectively). The isentropic curves from equation (F2) and a least squares fit to all data points greater than 0.001 for the acoustic ratio are also plotted in the figures. This demonstrates that the isentropic curve is sufficiently accurate. In figure 50(b), it is apparent that more data points, especially at higher acoustic ratios, are needed to better establish the compressibility curve.

Figure 51 is the plot of the computed value of calibration coefficient as a function of pipe Reynolds number for both F-146 and F-147. There is an unexplained anomaly in the flow coefficient calibration curve for F-147. It can be seen that the curve decreases to a minimum value and then increases again with increasing Reynolds number; whereas, the normal curve, like the curve for F-146, becomes asymptotic to a constant value of flow coefficient at large Reynolds numbers. The scatter in the data points in figure 51 is within ±0 5 percent, and this is approximately the tolerance on flow coefficient given
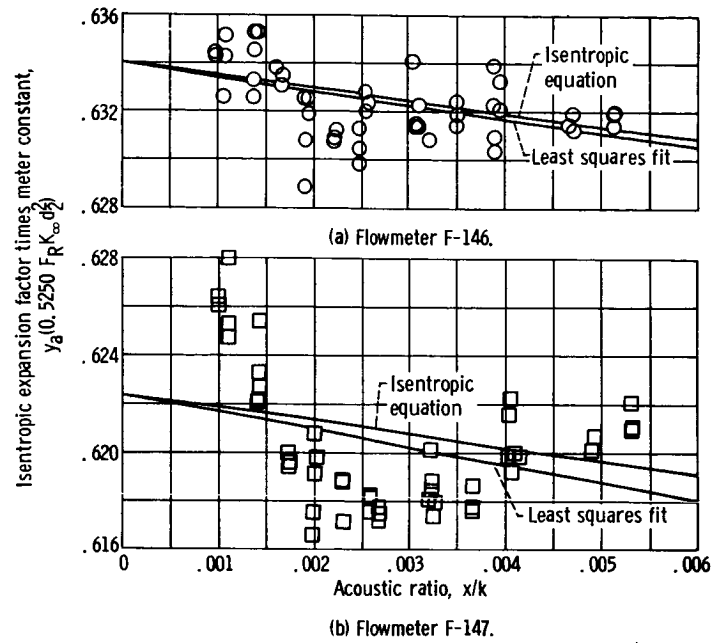
(a) Flowmeter F-146.

(b) Flowmeter F-147.

Figure 50. - Isentropic expansion factor as function of acoustic ratio.
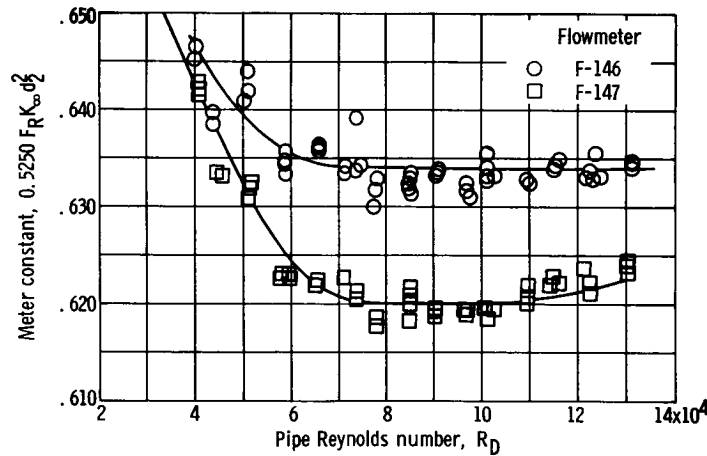

Figure 51. - Meter constant as function of pipe Reynolds number.

for square-edged orifices in reference 15. For this reason, figure 51 contains acceptable calibration data.

Mass Flow Computation

Examination of equations (F1) and (F3) and figure 51 shows that an explicit solution for the mass flow rate is lacking. The solution is therefore found by iteration as

follows: An approximate value for w_s is determined from equation (F1) by assuming $F_a F_R Y_a = 1$ and using values for the calibration coefficient $0.5250 \, K_\infty d_2^2$ of 0.6224 and 0.6340 for F-147 and F-146, respectively. These values of K_∞ are obtained from figure 51 by assuming $R_D = \infty$. The value of w_s so obtained is used in equation (F3) to calculate R_D. The new value of R_D can then be used in figure 51 to get a more accurate value for the calibration coefficient. The new value of calibration coefficient can be substituted into equation (F1), and with the proper values of F_a and Y_a and an exact mass flow rate w_s can be found.

The value of Δp in the preceding calculation for each flow computation can be determined from the flow recorders F-146 and F-147. The upstream gas density for F-146 is determined from the temperature and static pressure at the upstream locations of T-121 and P-103, respectively. Since pressure and temperature are not measured directly upstream of F-147, supplementary tests were made which indicated that the static pressure could be obtained from P-103 by subtracting from P-103 an amount equivalent to the friction pressure drop through F-146, which amounts to approximately 0.32 times the F-146 differential pressure. The same supplementary tests indicated that T-121 was sufficiently close to be used for the F-147 upstream temperature.

This computation of w_s is programmed into the Plum Brook Reactor Facility data-logger computer, and can be performed at two minute intervals if necessary.

APPENDIX G

SAFETY ACTION DELAY TIME MEASUREMENTS

Purpose

These measurements were made to verify that the interval between the time of a step change of a variable to an unsafe level and the time at which safety action is initiated is no greater than the delay times assumed for hazard analyses.

Description of Equipment and Circuitry

Figure 52 gives a diagram of the circuitry used in this test. The silicon control rectifier (SCR) was used as a switch to provide step changes in voltage. The SCR is set into conduction by pressing the "step" pushbutton. The circuit is reset by pushing the "reset" pushbutton, which places the reverse voltage formed on capacitor C1 in parallel with the SCR. A voltage divider and control pot are used to reduce the voltage step to the desired amplitude. The position of the double-pole, double-throw switch determines the polarity of the step seen at the step output terminals. A battery and voltage divider with a control pot is used to provide the simulated direct-current signal level. The step change is added to the direct-current level by connecting the step and direct-current output terminals in series. A universal EPUT meter and timer were used in the TIM X-Y mode. In this mode, the instrument measures the interval between an event at input X and an independent event at input Y. Input X, in this case, is the step voltage input from the SCR. Input Y comes from the step change in voltage which results in the opening of the B-contact of the scram relay in the channel being tested.

Test Procedure

The delay time of each safety channel was measured for a step change from the normal operating level to the safety set point. For the case of flowmeters F-147 and F-147A, where a large range of operating levels can exist, the level chosen was the one that resulted in the greatest possible delay time. Ten measurements were made and recorded for each channel.
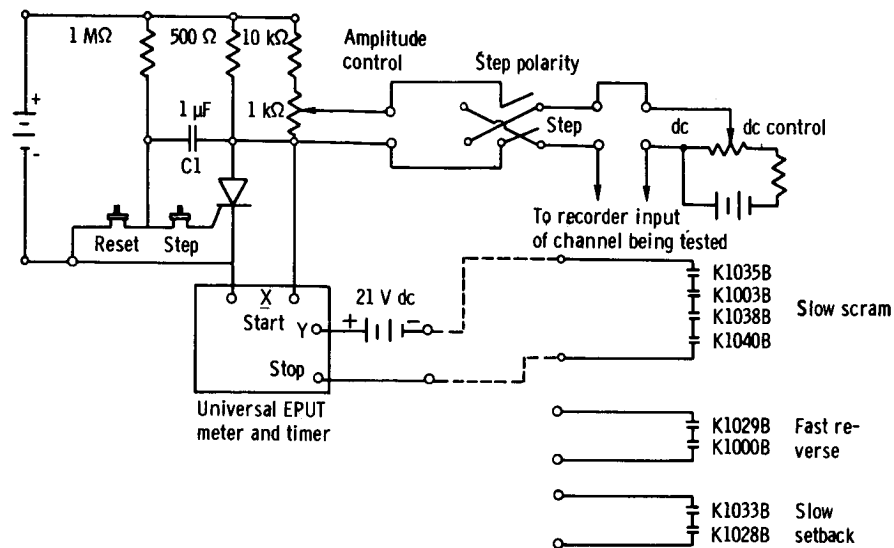
Figure 52. – Time delay measuring circuitry.

TABLE XVII. – DELAY TIME DATA

Recorder	Normal reading	Safety set point	Measured delay time, msec											
			1	2	3	4	5	6	7	8	9	10	Average	Maximum
F-147	0.24 lb/sec	0.10 lb/sec	203	205	205	203	199	208	209	195	209	209	204.4	209
F-147A	0.24 lb/sec	0.10 lb/sec	198	199	194	195	193	192	194	196	200	193	193.4	200
PR-107	179 psia	125 psia	393	393	395	391	388	398	387	385	390	391	392.1	398
TR-522	235° F	300° F	369	362	299	362	300	298	367	297	299	297	325.0	369
TR-128	385° F	600° F	315	315	316	307	312	309	314	308	305	304	310.5	315
	580° F	900° F	395	392	401	392	398	397	387	398	389	393	393.2	401
TR-128A	385° F	600° F	383	380	377	381	374	375	373	380	379	374	377.6	383
	580° F	900° F	451	441	442	444	446	446	447	442	446	449	445.4	451
PR-503	35 psia	45 psia	241	244	238	249	241	242	247	241	238	249	243.0	249

Results and Conclusions

The ten measured delay times, the maximum delay time measured, and the average delay time for each safety channel are given in table XVII. Where two sets of operating conditions and set points appear in the table, the first is for a proposed 50-kilowatt test and the second for a proposed 100-kilowatt test. In considering the overall response

time of the instrument channels. the response of the transducers must also be considered. The calculated full-scale response times for the particular transducers and thermocouples involved were no greater than 15 milliseconds; therefore, they were ignored. None of the measured delay times exceeded the values assumed in the hazards analyses.

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